NIWA

Taihoro Nukurangi

Meteorological Hazards to Hawke's Bay Engineering Lifelines

NIWA Client Report WLG99/78
October 1999

OCTOBER 1999
AM 00/01
HBRC plan No. 2879

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Prepared for

Hawke's Bay Engineering Lifelines
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DISCLAIMER

The information and data presented in this report are based on the best information available to NIWA at the time of writing. The climate data used here were available from only a limited number of locations. The frequency and extreme nature of meteorological hazards deduced from these data contain uncertainties. NIWA does not accept liability for any outcomes resulting from the use of this report and its contents.

NIWA Client Report WLG99/78
October 1999

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Contents

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Introduction to this report

The Hawke's Bay Engineering Lifelines Project is collecting information on all major potential natural hazards in Hawke's Bay. This report, compiled under contract to the Hawke's Bay Engineering Lifelines Steering Committee, has been undertaken by NIWA (The National Institute of Water and Atmospheric Research Ltd.), and provides information on the *meteorological* hazards of the Hawke's Bay region.

The main meteorological hazards of concern to Hawke's Bay Engineering Lifelines (HBEL) are:

- Windstorms
- Extreme rainfall
- Snow
- Drought

Level of hazard

For the purposes of this study, two 'benchmark' levels of severe meteorological hazards have been considered. The first is to take some extreme events from the archived climate data record for Hawke's Bay, and to determine from this record how often such events are likely to occur. This average frequency of recurrence, (or average return period), is a useful indication of how often resources that are designed to cope with such events might be needed.

A second benchmark for the measurement of extreme events has been linked by HBEL to the frequency of severe earthquakes, in this case with average return periods of 142 and 475 years. Because meteorological observations have not been recorded for as long as this, estimates of the severity of meteorological events for these return periods have been obtained by extrapolating from available data. Estimates obtained in this way are uncertain, because such extreme events may have never been measured. However we believe that such estimates can be used with reasonable confidence to plan for lifelines protection.

1 Windstorms

1.1 Maximum wind gust speeds

The strongest winds in Hawke's Bay are typically from the west (often channeled along river valleys), and are usually associated with active frontal passages. High winds from the west are a common occurrence in the western ranges and along the foot of the lower mountains, as well as in exposed east-coast hills (such as Cape Kidnappers and the Mahia Peninsula). They are relatively infrequent in many lowland areas.

Strong winds also occur from the southerly and easterly sectors, being associated with deep depressions centered to the east or north of the region. High winds occurred over the lower North Island at the time of the passage of the *Wahine Storm* during 8-12 April 1968, as the centre of a deep depression (ex-tropical cyclone *Giselle*) passed directly over Hawke's Bay. Only a little is known of the maximum winds in the Hawke's Bay region during that event, as Napier Airport was the only wind recording station in operation at the time. Although the winds were much less severe than those experienced in Wellington and southern Wairarapa, mean speeds reached gale force (63 km/h) at Napier Airport, and were high enough to cause considerable damage to trees and buildings in and about Napier City and Hastings. More recently, violent storm force winds from the south were reported at the Port of Napier (mean speed 103 km/h) during the passage of *Cyclone Bola* on 8 March 1988.

Extreme maximum wind gusts (i.e. maximum recorded wind speeds with a nominal duration of three seconds), and frequencies of strong winds over various threshold values for lowland Hawke's Bay sites, are shown in Table 1.1 below. Although Dannevirke and Castlepoint are outside the region, their data have been included in the table as examples of high wind speeds that are likely to be experienced in Central Hawke's Bay.

Table 1.1 shows that for most locations the highest wind speeds are from the west, with exposed southern coastal gust speeds likely to be higher than gust speeds for low-lying areas. In the table we have included the maximum wind speeds during the *Wahine Storm* (*Giselle*) and *Cyclone Bola* for comparison.

Table 1.2 shows frequencies of wind gusts near gale force (59 km/h) and storm force (93 km/h). Frequencies of strong winds will typically be higher over exposed mountain ridges, summits and hilltop locations, than in the coastal and plains areas represented by the sites listed in the table.

Table 1.1 Extreme maximum wind gusts (km/h) at selected Hawke's Bay sites. Extreme gusts are the maximum-recorded wind speeds with a nominal duration of three seconds.

Station	Period	Max. gust	Date	Giselle (10 Apr 1968)	Bola (7-8 Mar 1988)
Wairoa Airport	1954-1957	107 from 180°	14 Jul 1955	-	-
Mahia Automatic	1991-1999	146 from 260°	15 Jul 1998	-	-
Napier Airport	1948-1989	130 from 260°	17 May 1977	No gust data. Mean speed 65 from 250°	78 from 150°
Havelock North EDR*	1987-1994	78 from 270°	4 Oct 1988	-	-
Whakatu EDR	1997-1999	96 from 280°	31 May 1998	-	-
Dannevirke	1961-1964	137 from 280°	15 Apr 1962	-	-
Castlepoint	1972-1999	183 from 300°	19 Oct 1998	59 from 140° and later, 59 from 240°	85 from 150°

* Climate instruments affected by trees or buildings

Table 1.2 Mean annual wind gust frequencies (days per year) at selected Hawke's Bay sites. Wind gust speeds are averaged over three seconds.

Station	Period	Days per year with gusts > 59 km/h	Days per year with gusts > 93 km/h
Mahia AWS	1991-1999	79	5
Napier Airport	1948-1989	52	2
Napier Airport AWS	1991-1999	53	1
Havelock North EDR*	1987-1994	3	0
Whakatu EDR	1997-1999	26	1
Dannevirke	1961-1964	79	5
Castlepoint Light	1972-1990	191	55
Castlepoint AWS	1994-1999	225	109

* Exposure affected by trees or buildings

The data in Table 2.1 above show that on average there are at least 50 days per year in coastal localities where wind gusts exceed 59 km/h. Such gust speeds would be sufficient to cause dust storms and damage to light structures such as tents. It would be difficult, for example, for cars to tow caravans, and, at Napier Airport, crosswinds of this speed would prevent small aircraft landings. There are much fewer cases of storm force wind gusts (93 km/h or more). Gusts of this nature are strong enough to uproot trees and cause structural damage to buildings.

1.2 Severe windstorms

The ranges bounding the region to the west and northwest are subject to frequent high winds. The action of the wind flowing over the ranges disturbs the airflow through the whole depth of the atmosphere. Within the troposphere where moist conditions allow clouds to form, the disturbances are evidenced by the smooth lenticular-shaped clouds above the ranges. On the east side of the ranges, high winds are common along the downslopes of the ranges and out some distance from the foot of the ranges. These are part of the same mountain wave process and it is this phenomenon which is thought to determine most of the extreme winds in Hawke's Bay.

High-resolution weather models to simulate extreme wind phenomenon for locations where there are no anemometers are currently under development. Indicative results from an extreme wind model for wind gust speeds at Mahia Peninsula, Napier Airport, and Castlepoint are given below.

Probable 142 and 475 year wind gust speeds

Table 1.3 shows the maximum observed gust speeds, (from Table 1.1), and modelled maximum 3-second gust speeds that are likely to be equaled or exceeded at average intervals of 142 years (centre) and 475 years (right). The modelled speeds are higher than the maximum wind gusts observed at all three sites, indicating that both 142 and 475 year gusts have not been experienced in the region since records began.

Table 1.3 Observed maximum wind gust speed (km/h) for two sites compared with probable 142 year and 475 year return period gust speeds.

Location	Max. observed gust (km/h)	142 modelled speed (km/h)	475 modelled speed (km/h)
Mahia Peninsula	146	163	177
Napier Airport	130	140	153
Castlepoint	183	198	216

Acceleration factors for hill and mountain sites

It is important to note that design gust speeds for exposed locations, like mountain ridges, summits and hilltops, will be much higher than the modelled values given for low-lying more sheltered areas such as Napier Airport. Factors as high as 1.5 have been known in extreme cases.

The example data shown in Table 1.4 below suggest that gust speeds over the ranges to the west of Hawke's Bay may be higher than at Napier Airport by a factor of 1.5. This would indicate 142 year gust speeds of 210 km/h and 475 year speeds of 230 km/h.

In practice, the relationships between flat land and hill top gust speeds are highly variable, and measurements at specific sites would be essential to obtain more accurate information.

Table 1.4 Factors to be applied to flat-land gust speeds to obtain gust speeds on hilltops. (NZ Standards 4203, 1992).

Upwind slope gradient	Escarpments	Hills and ridges
0.08	1.04	1.09
0.10	1.08	1.18
0.20	1.18	1.36
0.03 and greater	1.24	1.54

2 Extreme Rainfalls

2.1 Floods in Hawke's Bay: Introduction

The earliest record of a severe flood in Hawke's Bay dates back to 1867. A detailed study (by the Soil Conservation and Rivers Control Council) was made in 1957, noting 91 floods of various severities in the 87-year period from 1867 to 1953. Flood descriptions taken from this study, and analysis of other more recent events, shows that there have been 15 major flood events this century, of which 85 percent occurred during the first six months of the year.

Major flooding in Hawke's Bay is frequently associated with depressions that originate in the Tasman Sea or tropics and then pass over the northern half of the North Island. When they are centered north of Hawke's Bay they bring strong, moist easterly or southeasterly airflow over the region. As these air masses ascend the ranges inland, they typically dump heavy rain, particularly at higher elevations, enhancing river flows into the plains. Rainfall can be prolonged especially if the frontal systems associated with the depression are slow moving.

There are also occasions when brief heavy rainfall can occur in a locality associated with afternoon thunderstorm build-ups, due to strong daytime heating, or from thunderstorms that are part of a frontal passage. Situations like this typically occur between October and April. They can result in localised high intensity rainfall – often in the space of 20 minutes to an hour with local surface flooding, causing occasional washouts and temporary power failures. A rainfall total of 91 mm in an hour has been recorded in this type of situation in Hawke's Bay.

2.2 Four severe floods in Hawke's Bay

As a background to understanding the types of rainfall events that can cause serious flooding in Hawke's Bay we have listed below brief descriptions of four of the most destructive floods of this century. These include the more recent *Cyclone Bola* event (6-9 March 1988), and the 10-12 March event in 1924. The latter flood was very notable due to the exceptionally intense rainfall, most of which occurred within 12 hours. A nominal *regional average rainfall,* and *percentage of stations recording rainfall totalling at least 100 mm* are listed in Tables 2.1 through 2.4, and example peak rainfalls at individual are noted separately in Tables 2.1a to 2.4a. Some *peak discharge* rates of major rivers have been included.

The *regional average rainfall* is the average of all available Hawke's Bay rainfall data for each event. This figure is useful at times in determining the relative ranking or severity of storms from a regional perspective.

The notes given below help to characterize the flood events in Hawke's Bay and point to some of the localities that were the most vulnerable. In all four floods, rainfall of at least 200 mm was recorded in the most affected localities, and this amount sometimes fell in less than 24 hours. In most cases, rivers overflowed, and floodwaters entered urban areas, or covered large areas of rural land. Landslips, damage to bridges, road or rail links, and stock losses were a consequence of these events.

Note that some of the information provided below was extracted from press reporting at the time of the events and therefore may not be completely accurate in describing the floods.

Flood 1: 10-13 June 1917

High rainfall occurred throughout the region, but it was especially high in Central Hawke's Bay. The Tutaekuri River flooded the Meeanee, Taradale, and Greenmeadows areas. The Ngaruroro River also broke its banks at Omahu, flooding Koropiko, Chesterhope, and Papakura. The approach to the Waitangi Bridge was washed away and stock losses were very severe. Damage to county roads and bridges was high.

Table 2.1. Daily rainfall (mm) for selected locations (recording at least 100 mm on any one day) from 10 through 13 June 1917. Totals are for 24 hours from 9 00 am on the date listed.

Number	Site Location	10 June	11 June	12 June	13 June	10-13 June Total
D96281	Tutira	43	213	213	41	510
D96471	Rissington	31	217	117	15	380
D96483	Eskdale	50	137	112	3	302
D96492	Napier, Waititerau	24	128	71	7	230
D96541	Whanawhana	25	175	71	1	272
D96561	Sherenden	41	277	87	0	405
D96591	Napier, Nelson Park	24	144	70	5	243
D96691	Havelock North, Te Mata	16	196	120	17	349
D96741	Gwavas	34	139	73	5	251
D96792	Mokopeka	0	26	200	128	354
D96891	Wamarama	0	59	131	50	240
D97043	Wairoa, Waiputaputa Station	0	55	103	133	291
	Percent of stations in Hawke's Bay with rainfall of at least 100 mm	Nil	50	40	17	
	Regional average rainfall (mm)		1-day 118	2 days 221	3 days 253	

Table 2.1a. The highest 1, 2 and 3-day rainfalls recorded during June 10 to 13, 1917 and their estimated return periods.

Site	Duration	Amount (mm)	Average return period (yrs)
Morere	1 day	319	140
Tutira	2 days	426	225
Tutira	3 days	469	200

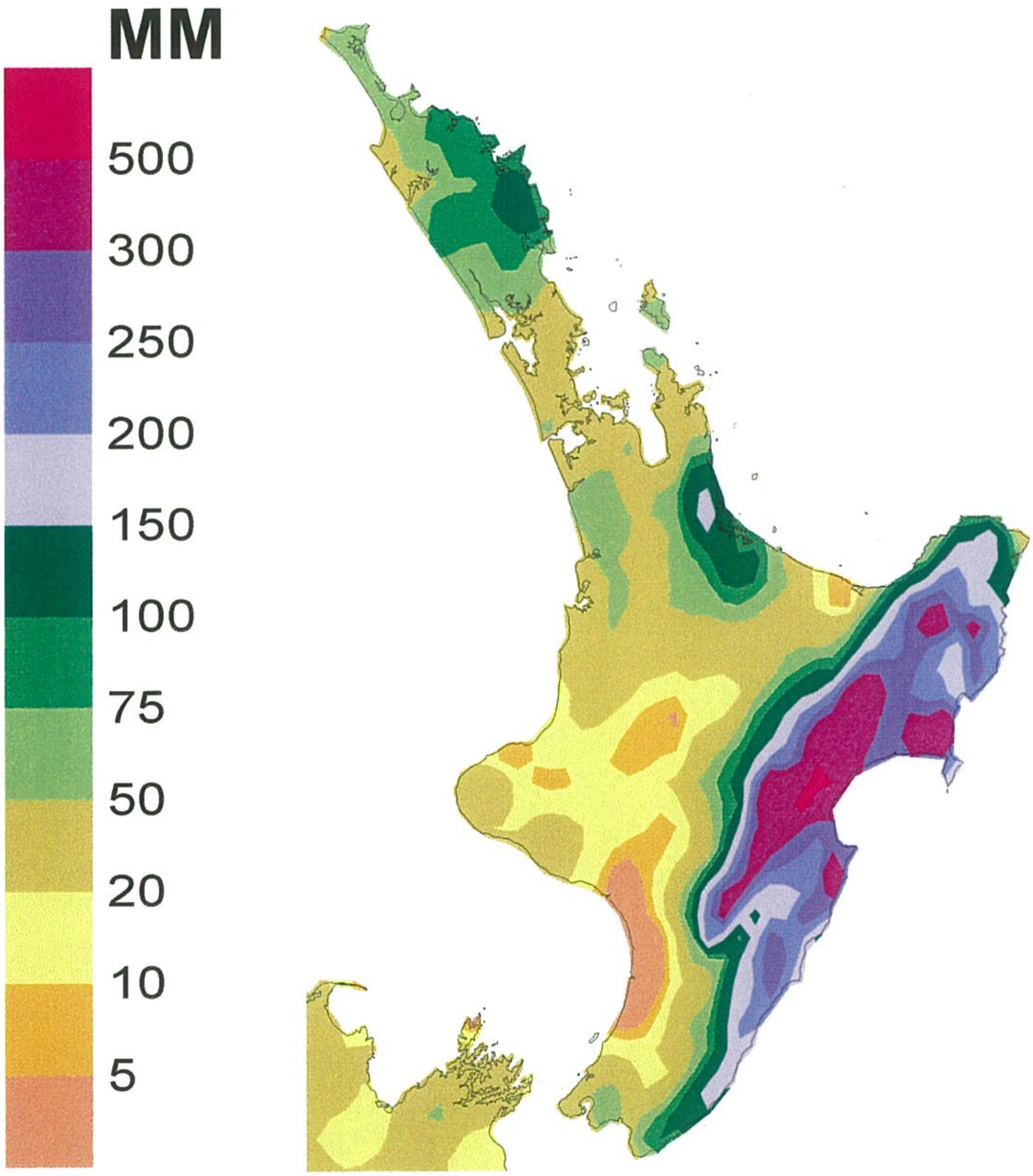


Figure 2.1 Total rainfall during the four days of 10-13 June, 1917

Flood 2: 10-12 March 1924

All rivers were in flood throughout Northern and Central Hawke's Bay, in many cases peaking at or above previous record flood levels. Flooding was widespread. The Ngaruroro River rose 1.8 metres in 35 minutes, with water swamping large tracts of land around Pakowhai and Clive. The Clive River bridge was severely damaged. There were considerable stock losses. The area between Meeanee was inundated with water, which rose to the tops of fences. The Taradale area was extensively flooded, and more than 200 people were evacuated. The Esk River rose to record levels. Flooding occurred in the main streets of Napier. Damage to roads, railways, and bridges was extensive. Two people lost their lives. Some houses were demolished by floodwaters. Nearby, Hastings had much less rainfall and suffered little or no flooding from the storm.

Table 2.2. Daily rainfall (mm) for selected locations (recording at least 100 mm on any one day) from 10 through 12 March 1924. Totals are for 24 hours from 9 00 am on the date listed.

Number	Site Location	10 March	11 March	12 March	10-12 March Total
D87761	Whakapunake	5	100	42	147
D96081	Te Rangi Maungaharuru	81	102	3	186
D96281	Tutira	51	344	10	405
D96471	Rissington	76	436	0	512
D96483	Eskdale	37	455	0	492
D96492	Napier, Waiititerau	9	277	1	287
D96561	Sherenden	25	104	47	176
D96591	Napier, Nelson Park	7	204	0	211
D97043	Wairoa, Waiputaputa Station	18	208	79	305
	Percent of stations in Hawke's Bay with rainfall of at least 100 mm	Nil	48	4	
	Regional average rainfall (mm)		1-day: 134	2-days:154	

Table 2.2a. The highest recorded rainfalls, for the durations noted, during the storm of March 10 to 12, 1924, and their estimated return periods.

Site	Duration	Amount (mm)	Average return period (yrs)
Tutira	8 hours	203	200
Rissington	2.75 hours	229	>500
Eskdale	9 hours	419	>500
Napier	9 hours	242	>200
Rissington	10 hours	512	>500
Eskdale	1 day	455	>500
Tutira	1 day	344	300
Rissington	1 day	436	>500

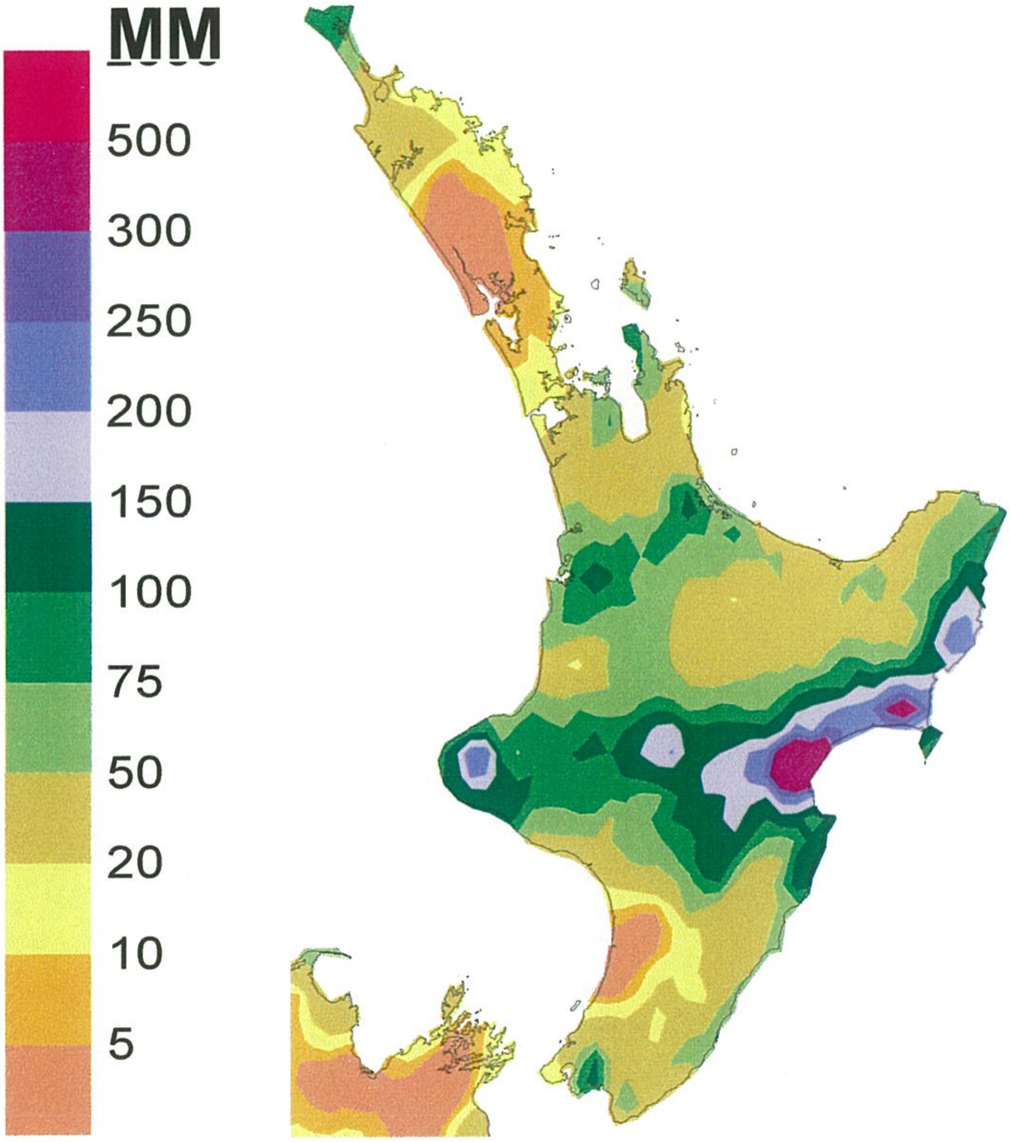


Figure 2.2 Total rainfall during the three days of 10-12 March, 1924

Flood 3: 23-26 April 1938

This appears to be the most severe Hawke's Bay flooding event on record. Widespread high rainfall occurred throughout the region, but heavy and very severe flooding affected northern and central areas, with unprecedented damage to roads, bridges, fences, livestock and other property. There was extensive and spectacular slippage of hillsides, and silting up to 3 metres in places, including on some major roads. Extensive damage resulted to public works, with 12 bridges washed away and 42 severely damaged. Floodwaters covered large areas of Clive, Meeanee, Taradale, and Papakura, as well as Napier and Hastings, with water up to 1 metre deep. Many families were evacuated, and others isolated. One life was lost. A considerable number of stock died, especially in the Esk Valley. The Mohaka River at Viaduct ran with a peak discharge of 6,370 m^3/s, and the Esk River recorded a peak discharge of 1,830 m^3/s.

Table 2.3. Daily rainfall (mm) for selected locations (recording at least 100 mm on any one day) from 23 through 26 April 1938. Totals are for 24 hours from 9 00 am on the date listed.

Number	Site Location	23 April	24 April	25 April	26 April	23-26 April Total
D06081	Rangitapu	6	104	132	38	280
D87711	Waikeremoana	60	147	188	27	422
D87731	Erepeti	38	131	120	33	322
D87771	Parikanapa	59	188	76	36	359
D87811	Waikaremoana, Onepto	52	182	153	20	407
D87812	Tuai	36	475	141	11	663
D87962	Mangaone Valley	65	184	114	136	499
D87981	Sea View Station	120	285	54	65	524
D96081	Te Rangi Maungaharuru	52	271	158	20	501
D96191	Putorino	102	419	295	20	836
D96251	Te Wairere	49	391	378	32	850
D96261	Rukumoana	89	197	208	20	514
D96281	Tutira	78	324	209	82	693
D96284	Waikoau	102	299	216	72	689
D96471	Rissington	85	254	151	6	496
D96541	Whanawhana	46	161	39	6	252
D96561	Sherenden	57	196	55	12	320
D96591	Napier, Nelson Park	26	169	79	17	291
D96681	Hastings	18	194	59	11	282
D96691	Havelock North, Te Mata	15	193	94	13	315
D96741	Gwavas	25	115	54	11	205
D96771	Koparakore	16	148	49	15	228
D96792	Mokopeka	38	225	135	18	416
D96831	Blackburn	59	125	57	6	247
D96861	Pukehou, Te Aute	19	124	41	17	201
D96881	Hapua	11	168	144	32	355
D96882	Anawai	47	277	273	61	658
D96891	Waimarama	7	175	116	21	319
D97043	Wairoa, Waiputaputa Station	34	179	144	53	410
D97041	Wairoa	24	194	58	25	301
	Percent of stations in Hawke's Bay with rainfall of at least 100 mm	7	85	46	2	
	Regional average rainfall (mm)		1 day 180	2 days 291	3 days 332	

Table 2.3a. The highest recorded rainfalls for the durations shown, and their estimated return periods, during April 23 to 26, 1938.

Site	Duration	Amount (mm)	Average return period (yrs)
Tutira	12 hours	305	>500
Putorino	1 day	419	>500
Puketitiri	1 day	391	>500
Te Wairere	2 days	769	>500
Putorino	2 days	714	>500
Puketitiri	3 days	1001	>500
Te Wairere	3 days	818	>500
Putorino	3 days	816	>500

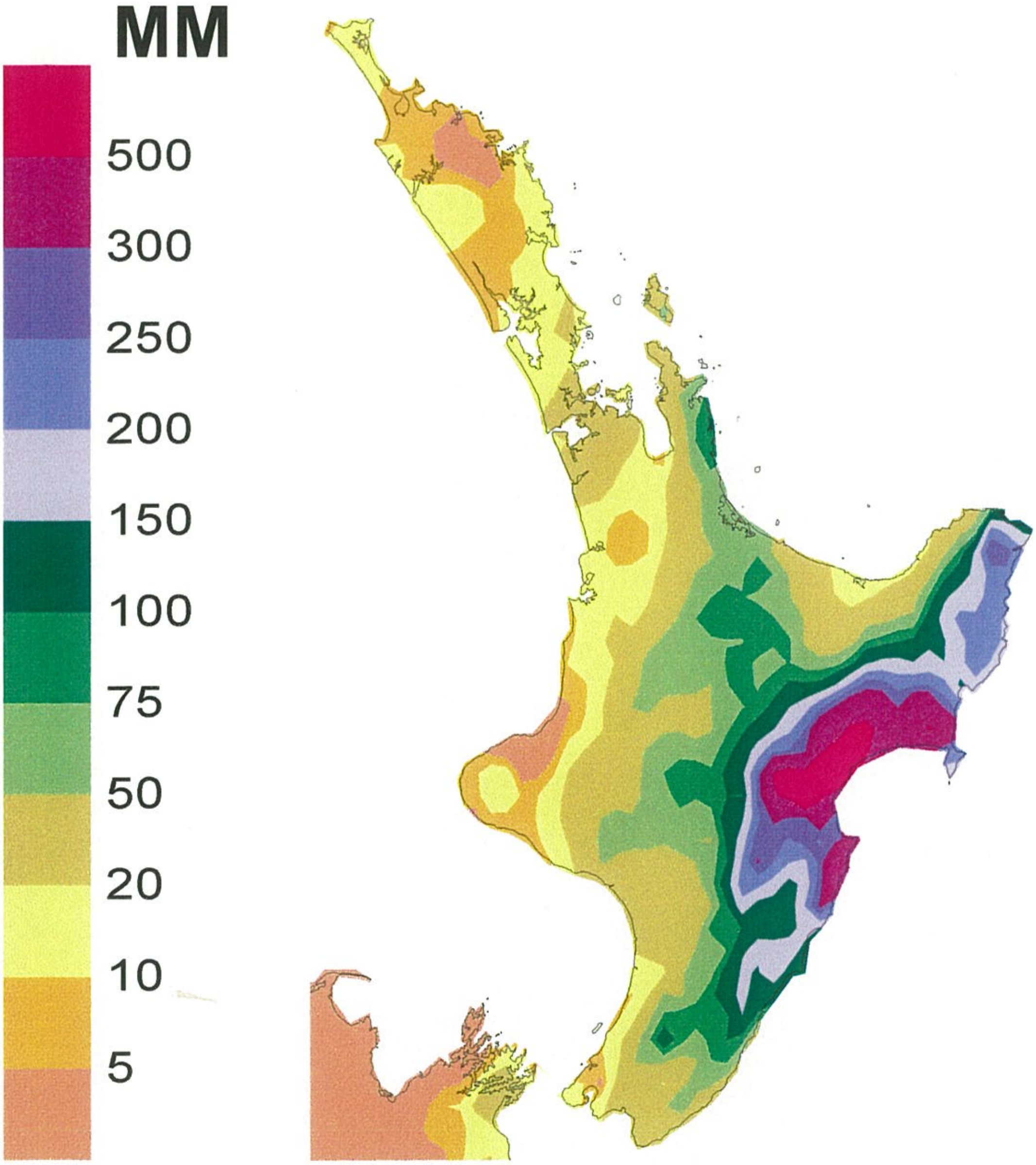


Figure 2.3 Total rainfall during the three days of 23-26 April, 1938

Flood 4: Cyclone 'Bola' 6-9 March 1988

This event was very severe with very extensive flooding, landslips and resulting damage in Northern Hawke's Bay, where a state of civil emergency was declared. Many roads and bridges were washed out north of Napier. This included the Wairoa Bridge, which was broken as a result of flood debris.

Table 2.4. Daily rainfall (mm) for selected locations (recording at least 100 mm on any one day) from 6 through 9 March 1988. Totals are for 24 hours from 9 00 am on the date listed.

Number	Site Location	6 March	7 March	8 March	9 March	6-9 March Total
D87713	Aniwaniwa	103	286	382	25	796
D87731	Erepeti	70	115	136	15	336
D87733	Mangatawhiti	60	166	100	14	340
D87771	Parikanapa	-	-	304	25	>329
D87781	Waingake	99	255	217	-	571
D87811	Waikaremoana, Onepto	121	191	191	15	518
D87812	Tuai	121	202	169	40	532
D87942	Clydebank, Frasertown	35	171	45	1	252
D96141	Black Stump Station	28	102	100	35	265
D96162	Te Pohue	49	190	246	49	434
D96251	Te Wairere	62	205	206	38	511
D96252	Ripia	25	113	93	18	249
D96261	Rukumoana	84	192	173	52	501
D96263	Titiokura	103	192	221	65	581
D96272	Esk Forest	78	203	174	36	491
D96281	Tutira	82	319	329	24	754
D96282	Tareha	-	202	223	188	<613
D96444	Kaweka Forest	41	96	159	71	367
D96451	Te Hau	38	101	156	42	337
D96452	Tahora	30	106	163	29	328
D96461	Hastings, Flagrange Road	32	111	139	20	302
D96483	Eskdale	60	133	106	7	306
D96561	Sherenden	48	83	161	13	305
D96731	Smedley	22	78	156	63	319
D96743	Gwavas Forest	-	53	105	43	>201
D96822	Brentwood	39	90	200	69	398
D96881	Hapua	15	84	129	27	255
D96882	Anawai	40	240	171	28	479
D96883	Valley Range	1	101	101	17	220
D97023	Waihua Valley	68	141	54	4	267
D97031	Wairoa, Waiputaputa Station	51	614	58	1	724
D97042	Wairoa, Frasertown	39	118	61	1	219
D97051	Tuhara Valley	38	113	65	27	243
D97076	Clonkeen	66	190	91	29	376
D97051	Mahia Beach	54	150	15	1	220
D97103	Potorino School	76	302	184	8	570
D97191	Pongaroa Station	0	191	25	0	216
	Percent of stations in Hawke's Bay with rainfall of at least 100 mm	6	45	40	1	
	Regional average rainfall (mm)		1 day 106	2 days 206	3 days 246	

Table 2.4a. The highest recorded 1, 2, and 3-day rainfalls in Hawke's Bay during *Cyclone Bola* and their estimated return periods.

Site	Duration	Amount (mm)	Average return period (yrs)
Aniwaniwa	1 day	382	>500
Aniwaniwa	2 days	668	>500
Tutira	2 days	648	>500
Waikaremoana	2 days	382	290
Aniwaniwa	3 days	771	>500

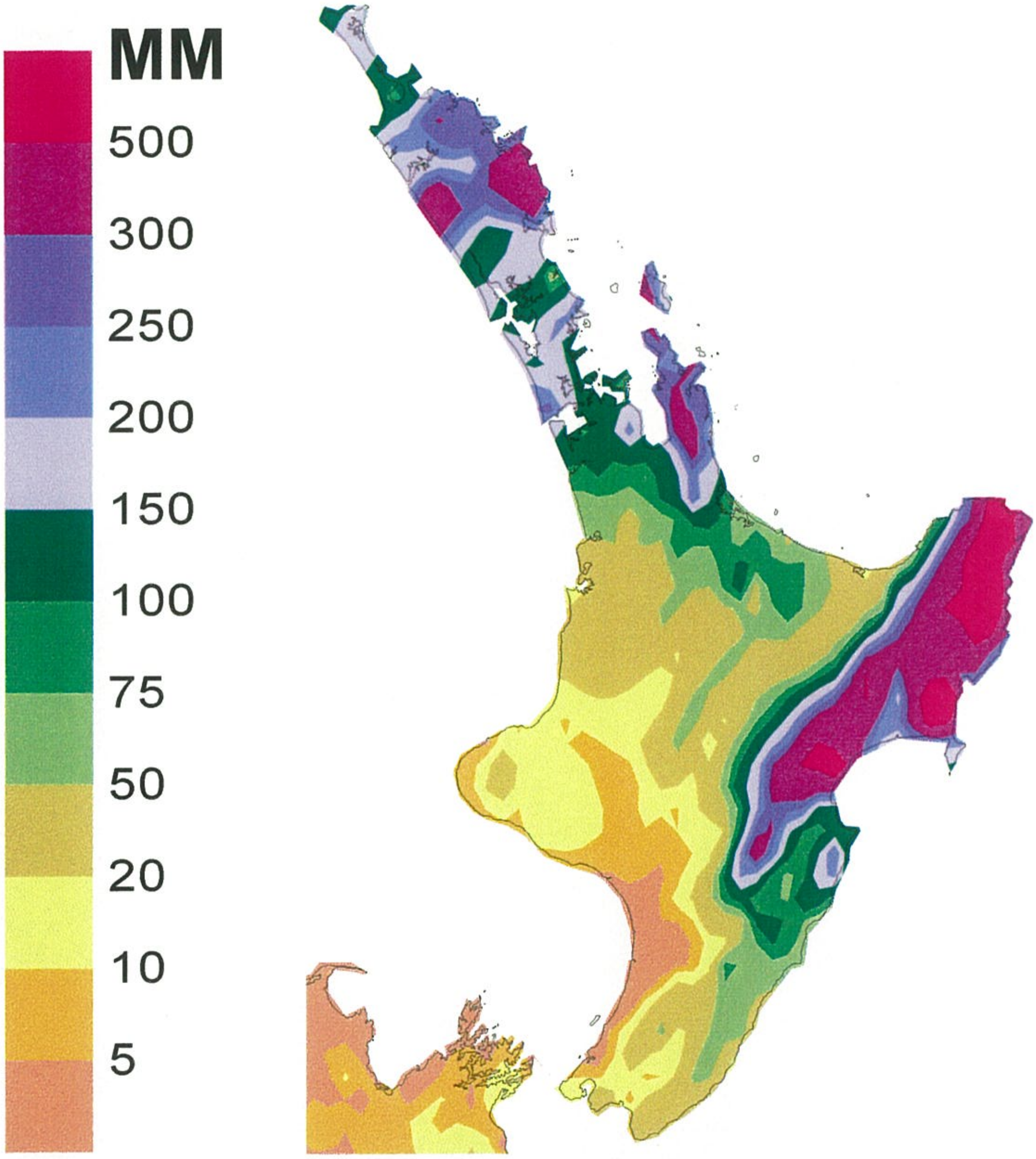


Figure 2.4 Total rainfall during the Cyclone Bola, 6-9 March, 1988.

2.3 Risk estimates for extreme rainfall events

In order to estimate storm rainfalls which could be expected at certain return periods in different parts of the Hawke's Bay, analyses of such storm rainfalls from a period of over 30 years was undertaken. For the purposes of the present HBEL study, the required return periods were 142 years and 475 years, which was consistent with the risk levels determined by HBEL for severe earthquakes.

A common method of analyzing extreme rainfalls at a given location is to fit an extreme value statistical distribution to a series of annual maximum rainfalls. In this study we have adopted the familiar *Gumbel* or extreme value type 1 distribution (Gumbel, 1958). There have been several studies (e.g. Beable and McKerchar , 1980; Tomlinson, 1980) which have shown this type of distribution to be suitable for estimating the return periods of high intensity rainfalls and river floods.

142 year and 475 year rainfalls

Gumbel analyses of one and two day rainfalls at a number of Hawke's Bay locations are appended to this Section. They provide estimates of rainfall depths for return periods of up to 1000 years. Rainfall depths for the 142 year and 475 year return periods required in this study were determined by a linear interpolation between the 100 year and 1000 year estimates. In doing so it has been assumed that there is no change in climate over the duration of time comparable to the return period (such as might occur due to global warming). Gumbel analysis of rainfalls at Sherenden, Waipukurau, Waikaremoana and Anawai showed that, on average, the 142 (475) year return period depths were 105 (122) percent of the 100 year depths.

Contour maps of estimated 24-hour rainfall depths for 142 and 475 year return periods are given in Figures 2.5-6 on the following pages. The rainfall contours are based on depth estimates by Tomlinson, (1980), and comprise 100 year estimates augmented by the enhancement factors given above (105 and 122% respectively).

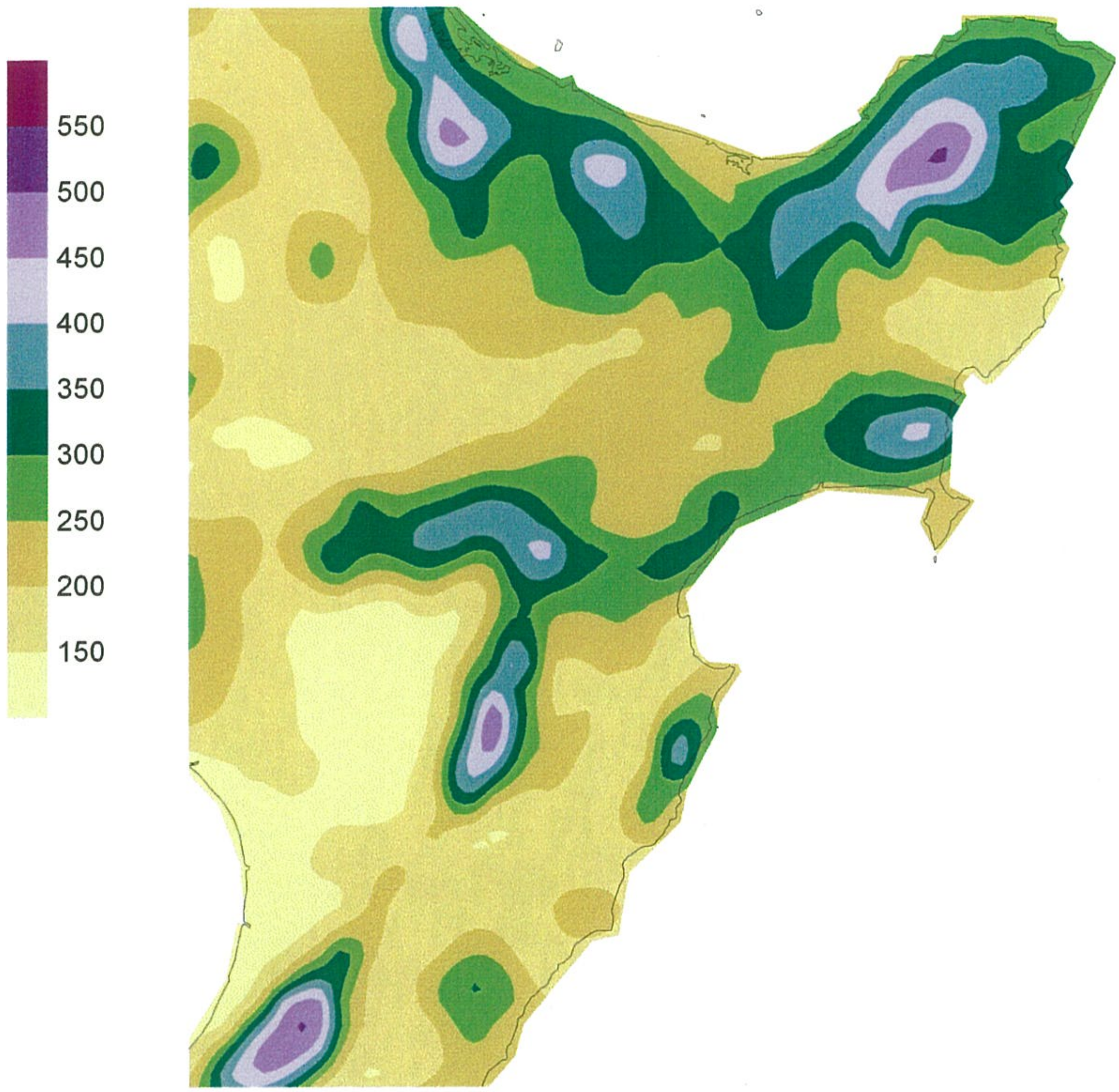


Figure 2.5 Spatial distribution of high intensity 24-hour rainfall (mm), that is expected to be equaled or exceeded at average intervals of 142 years. (Based on Tomlinson, 1980)

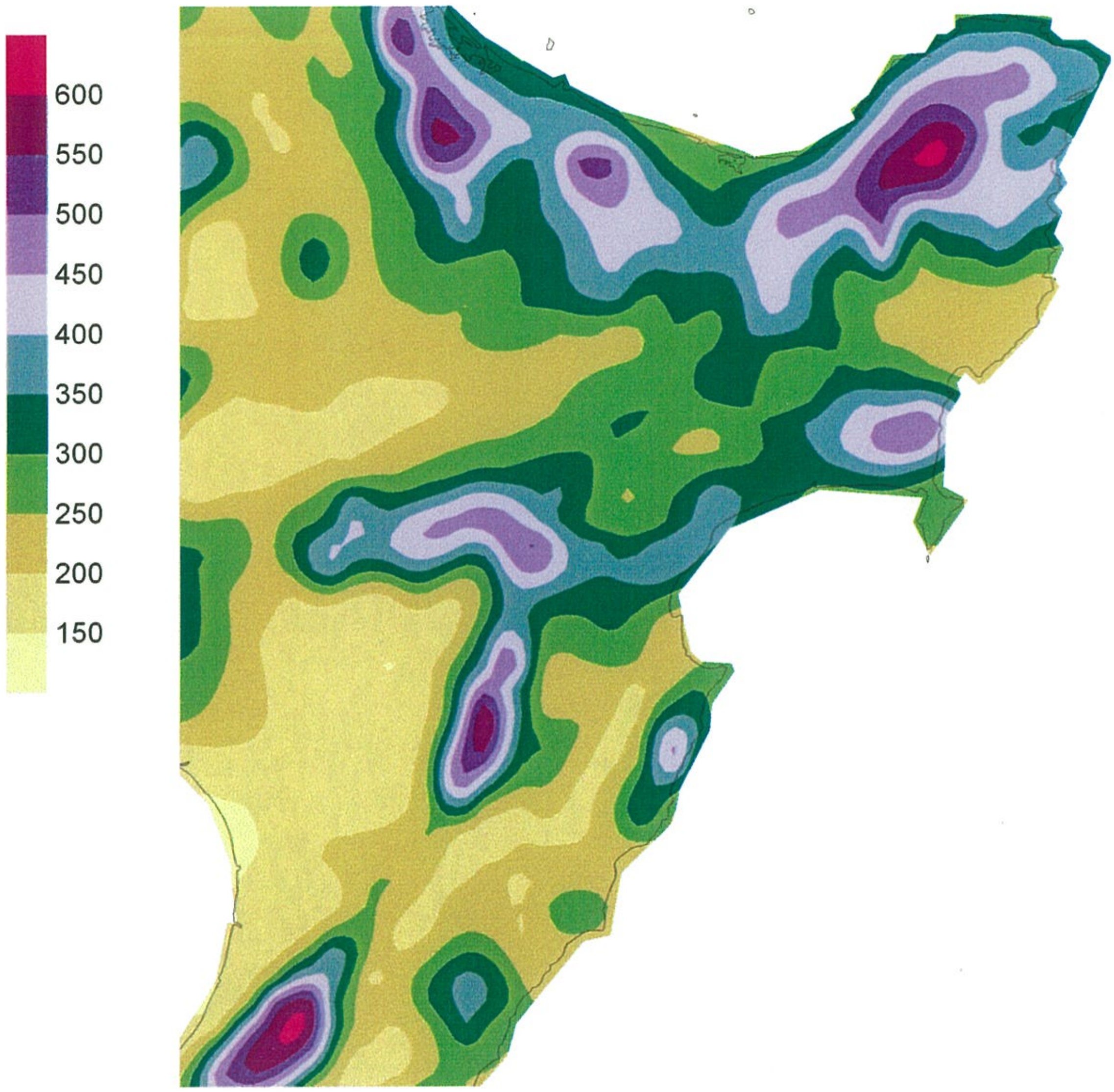


Figure 2.6 Spatial distribution of high intensity 24-hour rainfall (mm), that is expected to be equaled or exceeded at average intervals of 475 years. (Based on Tomlinson, 1980)

2.4 Storm duration ratios

Estimates of rainfall depths for other storm durations can be obtained by employing relevant depth-duration coefficients, given in Table 2.5, to the 100-year data used in contouring the above figures. The ratios in Table 5 were compiled from data covering New Zealand (Tomlinson, 1980) and are generally applicable to Hawke's Bay. The base intensity is the 24-hour fall (with a ratio of 1.00 on the table). For example, a 142 year, 12 hour high intensity storm near Napier could expect to have 77 percent of the 24-hour fall.

Table 2.5 Depth-duration ratios based on the 24-hour storm rainfall, for durations of 6 hours to 72 hours (after Tomlinson, 1980)

Duration (h)	6	12	24	48	72
Ratio (142 yr)	0.55	0.77	1.00	1.24	1.38

APPENDIX TO SECTION 2

1-day (9am-9am) annual extreme rainfalls and their return periods

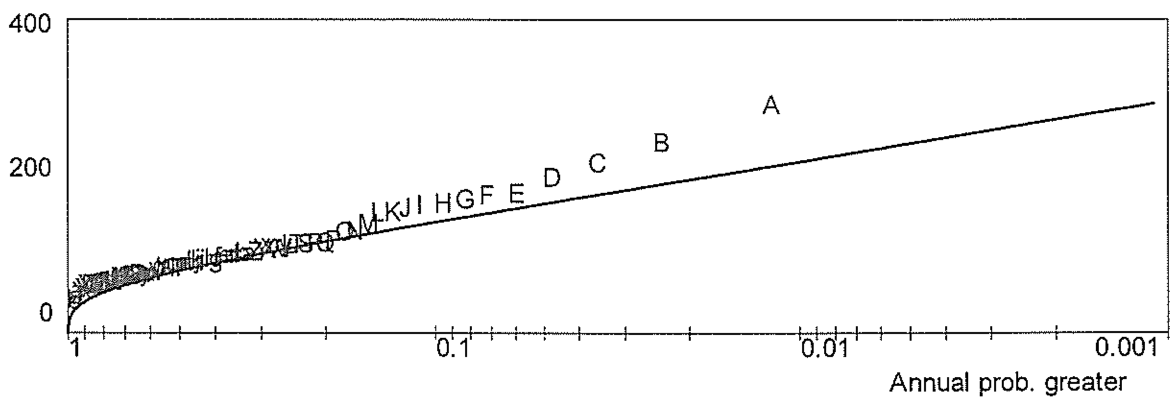
Gumbel distributions of 1-day and 2-day maximum observed annual rainfalls, indicating theoretical maximum falls with return periods of up to 1000 years.

Sherenden D96561

Columns shown in the table are:
Date: In the form of yymmdd (year, month, day)
Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record
Rain identification: The letters shown in the plotted position on the graphs below.
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.
Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.
Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			295	0.001	1000
11-Jun-1917	277	A	277	0.002	584
24-Jan-1938	229	B	229	0.007	135
			202	0.010	100
3-Jun-1963	202	C	202	0.016	61
			196	0.020	50
14-Mar-1985	184	D	184	0.029	35
			165	0.050	20
Mean	86				

Figure below: Gumbel distribution of 1-day rainfalls at Sherenden. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



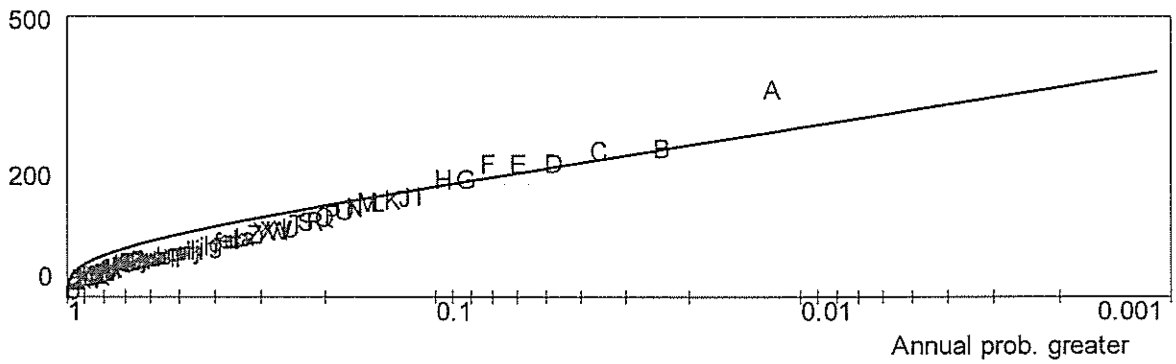
site 1396561 Sherenden 1308 thru 9505 rain mm m=12 Fmin=.00 Fmax=400.00
Gumbel Distn. Location & Scale= 67.12 32.94
A-b site 1396561 Sherenden 1308 thru 9505 rain mm m=12

Sherenden D96561

Columns shown in the table are:
Date: In the form of yymmdd (year, month, day)
Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record
Rain identification: The letters shown in the plotted position on the graphs below.
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.
Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.
Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			405	0.001	1000
11-Jun-1917	364	A	364	0.003	396
			302	0.010	100
			270	0.020	50
13-Mar-1985	269	B	269	0.021	48
23-Jan-1938	265	C	265	0.023	44
15-Apr-1971	245	D	245	0.035	29
7-Mar-1988	244	E	244	0.036	28
2-Jun-1963	244	F	244	0.036	28
			228	0.050	20
Mean	121				

Figure below: Gumbel distribution of 2-day rainfalls at Sherenden. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



site 1396561 Sherenden 1308 thru 9505 rain mm m=12 Fmin=.00 Fmax=1000.00
Gumbel Distn. Location & Scale= 95.03 44.90

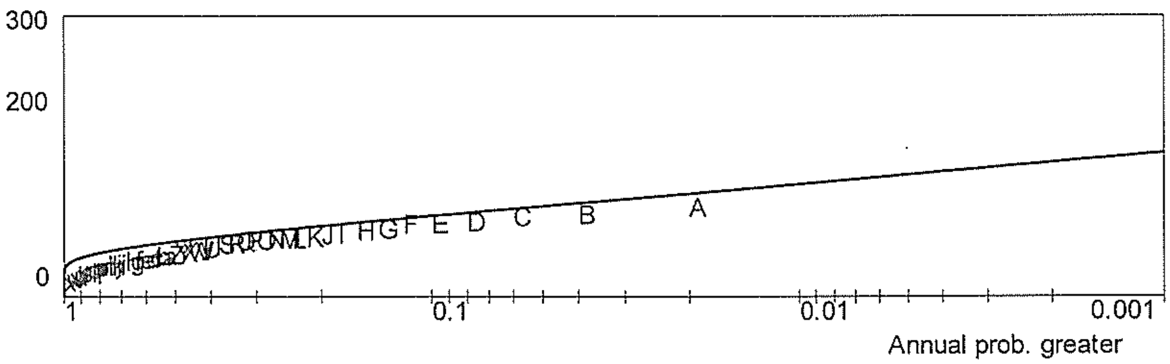
A-b site 1396561 Sherenden 1308 thru 9505 rain mm m=12

Waipukurau Airport D06051

Columns shown in the table are:
Date: In the form of yymmdd (year, month, day)
Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record
Rain identification: The letters shown in the plotted position on the graphs below.
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.
Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.
Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			153	0.001	1000
			120	0.010	100
			110	0.020	50
27-Jan-1953	104	A	104	0.030	33
18-Mar-1970	97	B	97	0.049	21
			97	0.050	20
Mean	62				

Figure below: Gumbel distribution of 1-day rainfalls at Waipukurau Airport. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



site 1306051 Waipukurau Airport 4501 thru 9408 rain mm m=12
Fmin=.00 Fmax=1000.00
Gumbel Distn. Location & Scale= 53.72 14.43

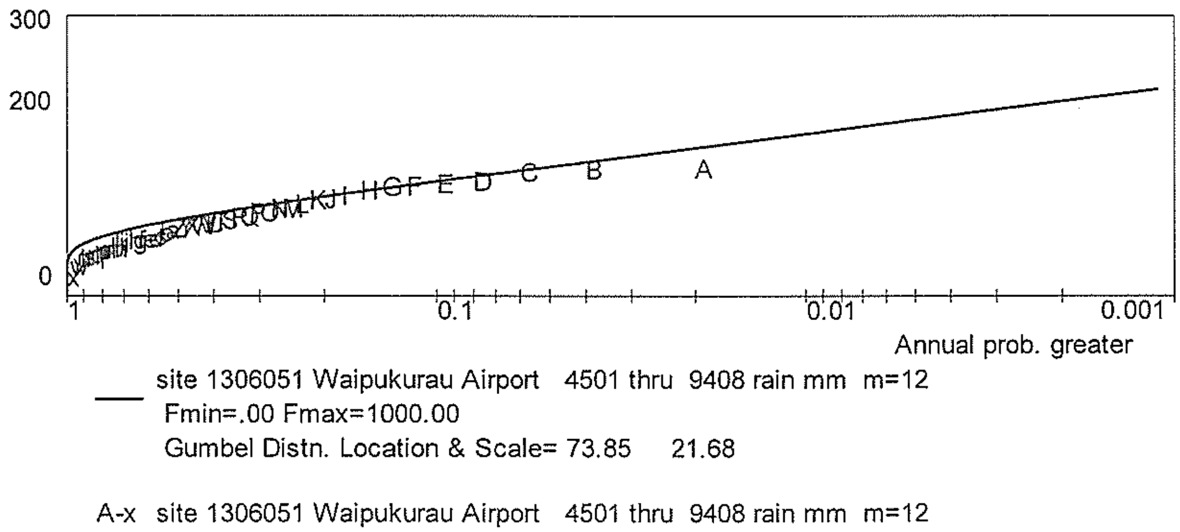
A-x site 1306051 Waipukurau Airport 4501 thru 9408 rain mm m=12

Waipukurau Airport D06051

Columns shown in the table are:
Date: In the form of yymmdd (year, month, day)
Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record
Rain identification: The letters shown in the plotted position on the graphs below.
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.
Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.
Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			224	0.001	1000
			174	0.010	100
			158	0.020	50
19-Mar-1979	141	A	141	0.045	22
9-Apr-1991	140	B	140	0.046	22
			138	0.050	20
17-Mar-1970	137	C	137	0.052	19
Mean	86				

Figure below: Gumbel distribution of 2-day rainfalls at Waipukurau Airport. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).

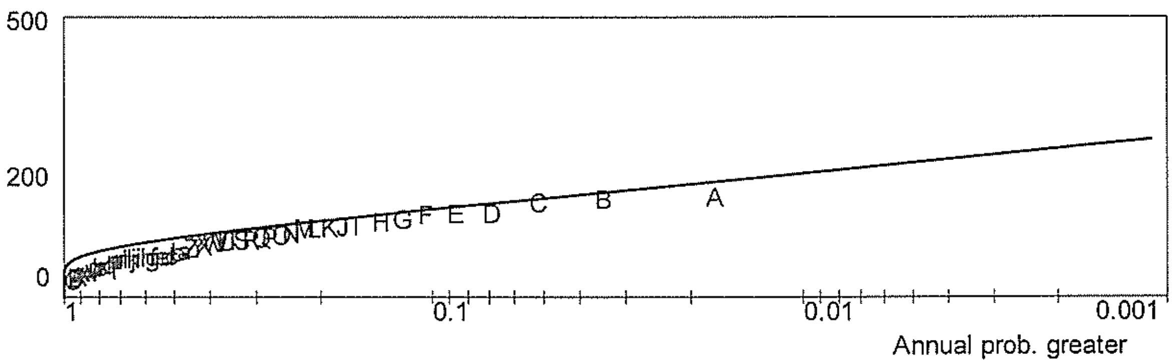


Waikaremoana D87811

Columns shown in the table are:
Date: In the form of yymmdd (year, month, day)
Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record
Rain identification: The letters shown in the plotted position on the graphs below.
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.
Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.
Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			284	0.001	1000
			221	0.010	100
			202	0.020	50
7-Mar-1988	191	A	191	0.029	34
18-Nov-1960	188	B	188	0.034	30
24-Apr-1938	182	C	182	0.041	24
			176	0.050	20
Mean	111				

Figure below: Gumbel distribution of 1-day rainfalls at Waikaremoana. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



site 1387811 Waikaremoana 3506 thru 9007 rain mm m=12 Fmin=.00 Fmax=1000.00
Gumbel Distn. Location & Scale= 95.01 27.38

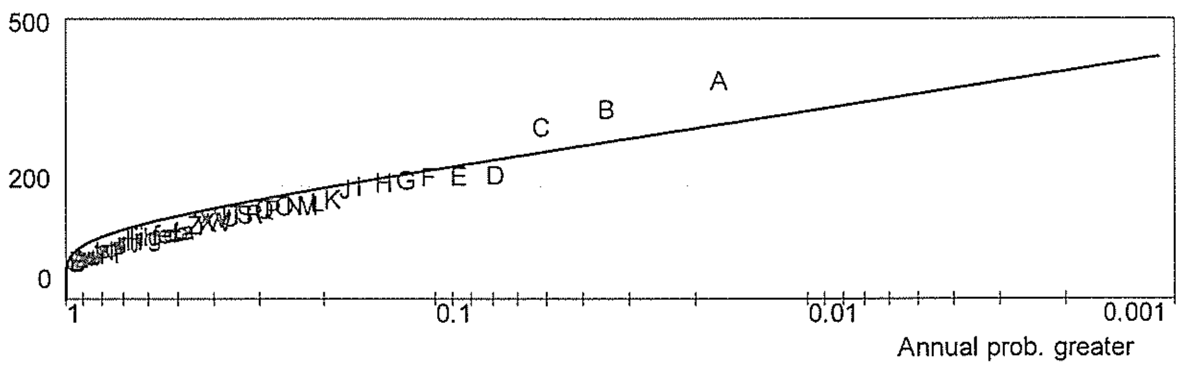
A-C site 1387811 Waikaremoana 3506 thru 9007 rain mm m=12

Waikaremoana D87811

Columns shown in the table are:
Date: In the form of yymmdd (year, month, day)
Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record
Rain identification: The letters shown in the plotted position on the graphs below.
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.
Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.
Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			437	0.001	1000
7-Mar-1988	382	A	382	0.003	291
24-Apr-1938	335	B	335	0.010	101
			335	0.010	100
18-Nov-1960	306	C	306	0.019	53
			304	0.020	50
			263	0.050	20
Mean	157				

Figure below: Gumbel distribution of 2-day rainfalls at Waikaremoana. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



site 1387811 Waikaremoana 3506 thru 9007 rain mm m=12 Fmin=.00 Fmax=1000.00
Gumbel Distn. Location & Scale= 131.6 44.19

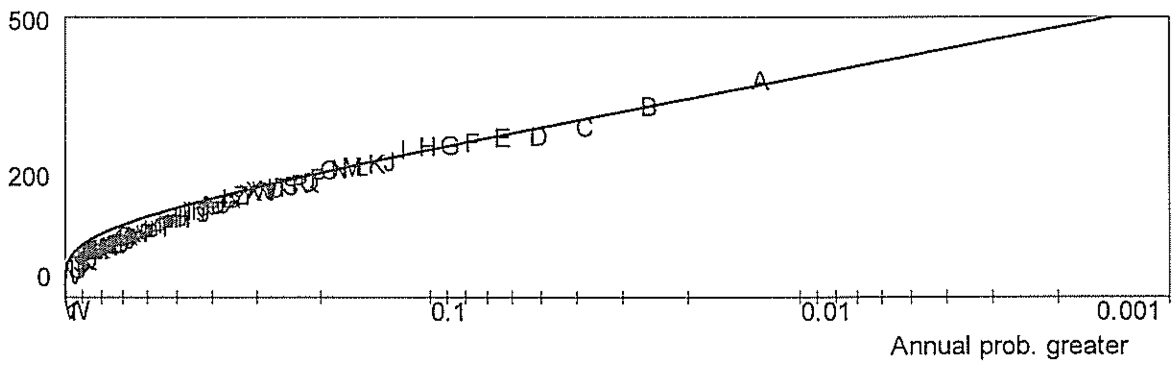
A-C site 1387811 Waikaremoana 3506 thru 9007 rain mm m=12

Anawai D96882

Columns shown in the table are:
Date: In the form of yymmdd (year, month, day)
Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record
Rain identification: The letters shown in the plotted position on the graphs below.
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.
Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.
Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			512	0.001	1000
			393	0.010	100
16-Jan-1961	380	A	380	0.013	79
			354	0.020	50
11-Mar-1955	338	B	338	0.027	37
23-Oct-1971	305	C	305	0.049	21
			303	0.050	20
Mean	171				

Figure below: Gumbel distribution of 1-day rainfalls at Anawai. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



site 1396882 Anawai 2507 thru 9909 rain mm m=12 Fmin=.00
Fmax=1000.00
Gumbel Distn. Location & Scale= 139.2 55.12

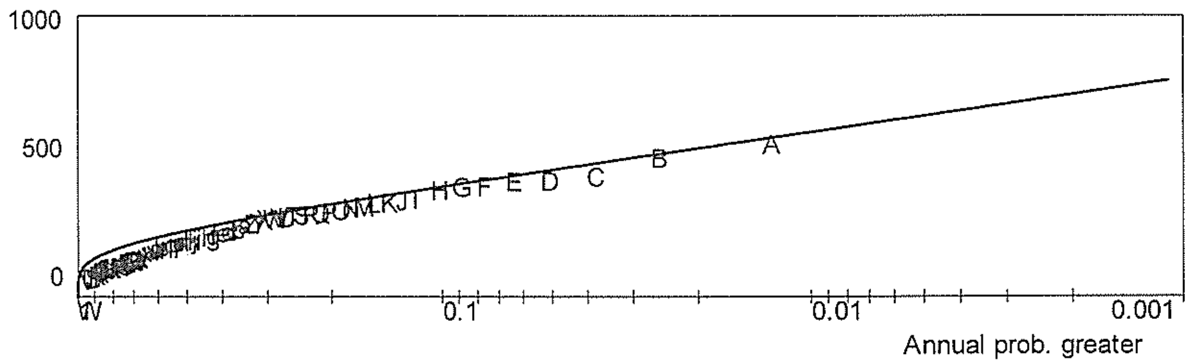
A-W site 1396882 Anawai 2507 thru 9909 rain mm m=12

Anawai D96882

Columns shown in the table are:
Date: In the form of yymmdd (year, month, day)
Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record
Rain identification: The letters shown in the plotted position on the graphs below.
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.
Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.
Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			777	0.001	1000
			586	0.010	100
24-Apr-1938	549	A	549	0.015	65
			528	0.020	50
13-Aug-1965	505	B	505	0.026	38
			451	0.050	20
28-May-1944	445	C	445	0.054	19
Mean	253				

Figure below: Gumbel distribution of 2-day rainfalls at Anawai. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



site 1396882 Anawai 2507 thru 9909 rain mm m=12 Fmin=.00
Fmax=1000.00
Gumbel Distn. Location & Scale= 205.0 82.80

A-W site 1396882 Anawai 2507 thru 9909 rain mm m=12

3. Snow

Snowfall is relatively uncommon in the plains areas of Hawke's Bay and there are few detailed or systematic records available. Some useful hill country records are available from the former DSIR site at Ballantrae near Woodville, from the Department of Conservation site at Aniwaniwa and the Whakapunake TV Station, and from sites at Waikaremoana, Makahu Saddle, Ngamatea, Gwavas Forest and Makaretu.

It is generally unclear how systematic the snow reports from these sites have been, although in each case there are relatively complete records for at least a few years.

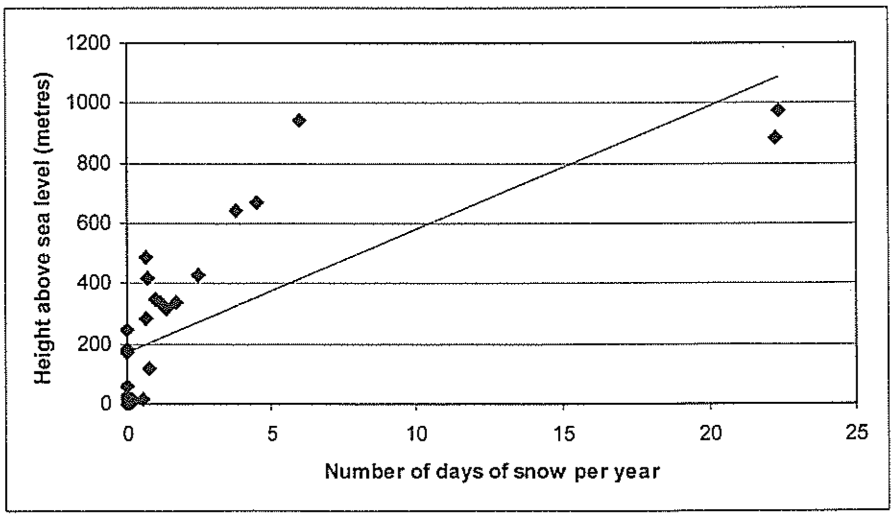
3.1 Frequency of snowfalls

It is reasonable to expect that snow falls are more likely in the higher hill country in Hawke's Bay than in the lower plains areas, and the snow fall observation data that are available generally support this. This simple but quite useful relationship can be put to use to estimate the number of snowfalls per year in places where there are no observations. By examining the relationship between recorded snowfall observations and the height of the observing station, a very approximate estimate of annual snowfalls can be derived for a range of land height intervals.

We have adopted this method here, and the result is displayed in Figure 3.1 below.

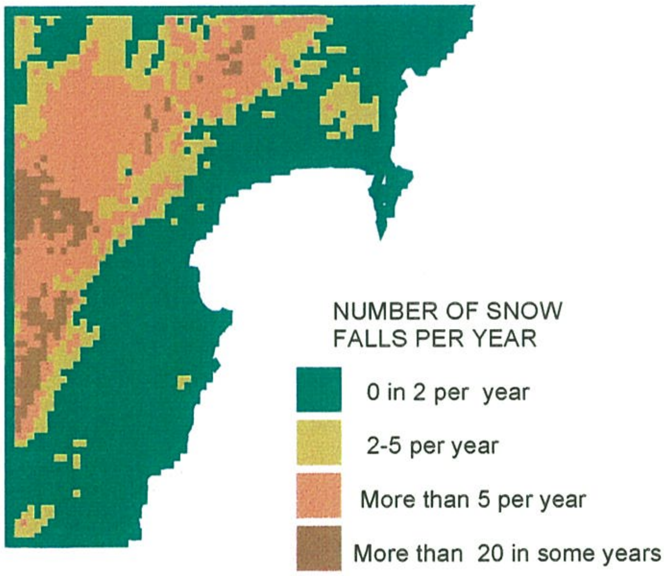
The data suggest that snowfalls are possible once or twice a year at altitudes below about 400 metres. At around 600 metres and above there are likely to be 5 or more snowfalls a year. More than 20 days of snowfall per year were reported at Makahu Saddle and Ngamatea, in the ranges in the south of the region.

Figure 3.1 Average number of days of snowfall per year reported at meteorological observing sites in Hawke's Bay.



An indication of the typical frequency of snowfalls, based on the relationship between altitude and snowfall reports, is shown in Figure 3.2 below.

Figure 3.2 Typical annual frequency of snowfalls in the Hawke's Bay region, based on the relationship between snowfall reports and height above mean sea level.



3.2 Extreme snow depths

The hill country bounding the region to the west and northwest can be subject to significant snowfalls. Snow depth data from Onepoto, Lake Waikaremoana (height 643 metres), have been extrapolated to estimate extreme snow depths (Gumbel 1958). Results from this method are given below.

Table 3.1 shows mean and maximum observed snow depths, as well as estimated maximum depths that are likely to be equaled or exceeded at average intervals of up to 475 years.

Table 3.1 Observed annual and maximum snow depths for Onepoto (Waikaremoana), compared with probable return period snow depths.

Onepoto, Waikaremoana (1936-1989)	
Mean annual maximum snow depth	7.4 cm
Top three maximum observed snow depths	22.9 cm (1 Aug 1939) 22.9 cm (4 Aug 1965) 21.0 cm (25 Jul 1987)
Mean annual days with snow lying to depths of:	
1 cm or more	1.45 days
1-4 cm	0.51 days
5-9 cm	0.47 days
10-14 cm	0.29 days
15-19 cm	0.11 days
20 cm or more	0.07 days
Return periods for annual maximum snow depths	
5 yrs	13 cm
10 yrs	17 cm
25 yrs	23 cm
50 yrs	27 cm
100 yrs	31 cm
142 yrs	33 cm
200 yrs	35 cm
475 yrs	40 cm

4. Drought

Droughts are hard to quantify and define, but are typically associated with periods when rainfall is much lower than the 'normal' amounts that have been determined from long term climate records. The timing and duration of droughts, and their degree of impact on one area compared with another, are all highly variable.

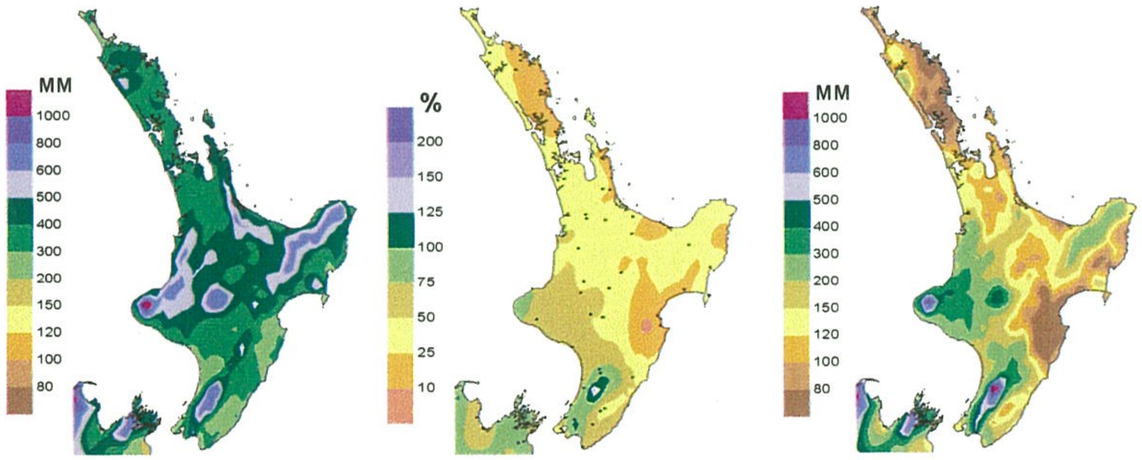
On the following pages we present rainfall patterns for a period of four months at the height of two major droughts, in the summers of 1945-46 and 1997-98.

In 1945-46 (Figure 4.1), rainfall from November 1 to February 28 was less than 25% of normal in most of Hawke's Bay, and less than 10% of normal in parts of the Heretaunga Plains. Drought conditions were widespread across much of the north and northeast of the North Island, and particularly severe in Hawke's Bay and Northland.

In the second example, the El Niño drought of 1997-98 (Figure 4.2), the driest conditions were more confined to the east coast, and rainfall was about 30-50% of normal in much of the area. The inland margins of the Hawke's Bay region were probably less severely affected by this drought than that of 1945-46.

Overleaf: Figures 4.1 and 4.2. Rainfall patterns for a period of four months at the height of two major droughts, in the summers of 1945-46 and 1997-98.

Rainfall analysis for: November 1945 to February 1946



Average November-February rainfall for all years.

Percentage of average rainfall 1 Nov 1945 to 28 Feb 1946.

Rainfall pattern, 1 Nov 1945 to 28 Feb 1946.

Fig. 4.1 1945/46 drought

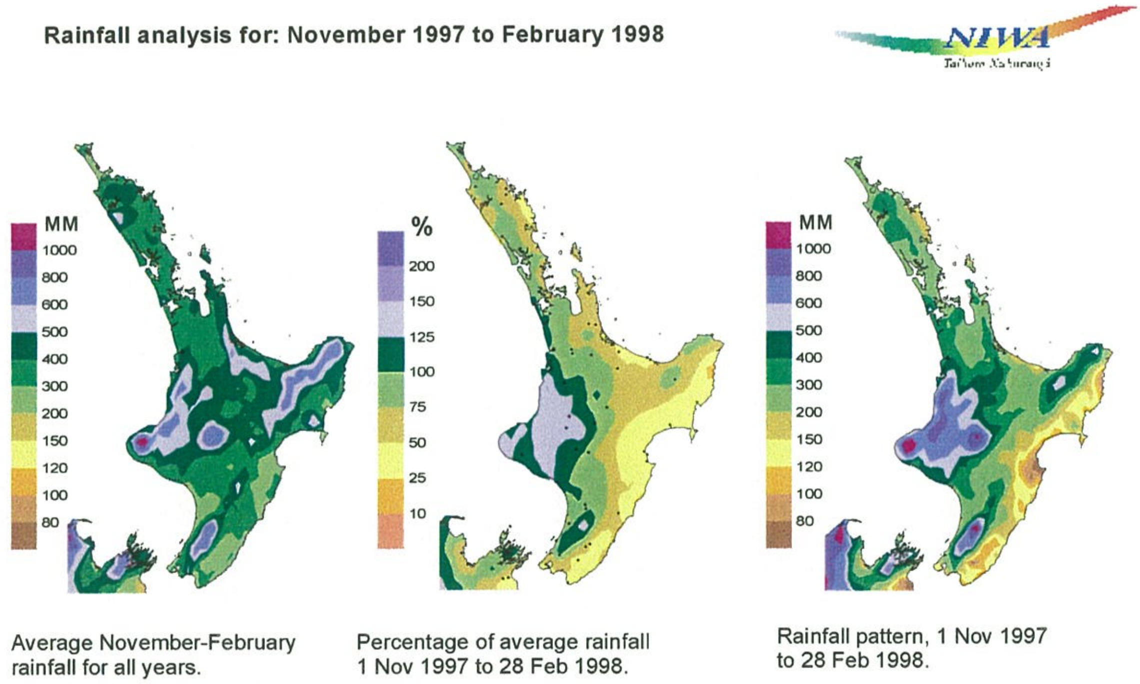


Fig. 4.2 1997/98 drought

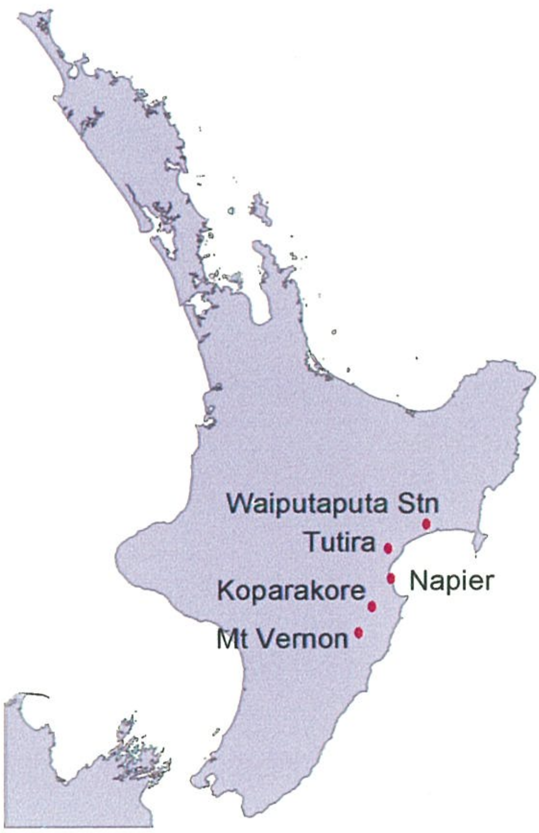
4.1 Periods of low rainfall during this century

In remainder of this section we provide an analysis of rainfall totals and their estimated return periods for four of the most extreme droughts that have occurred in Hawke's Bay during this century. These were the droughts that took place during the July to June years of 1945-46 and 1997-98 noted above, and also those of 1914-15 and 1982-83.

Five representative Hawke's Bay sites were selected for the analysis, from Waiputaputa Station near Wairoa in the north, to Mt Vernon Station near Waipukurau in Central Hawke's Bay. In each case the stations have reliable records going back to 1910 or earlier. The selected sites are shown on the map below.

The drought years were selected on the basis that in each drought there was a period of at least three months when the total rainfall was in the lowest decile, ie. a dry event with a return period of one in 10 or more years. It is noteworthy that in each of the four droughts selected, there was a three month period which was the driest on record at least one of the five sites.

Figure 4.3 Representative Hawke's Bay sites used in the low rainfall analysis.



4.2 Selection of low rainfall periods

Summary data and analysis of the rainfalls recorded during the four droughts are shown in the tables on the following pages. Three sets of data are presented for each site and drought, covering periods of three, six and nine months. A three-month period of low rainfall will typically have adverse effects on pasture production and water resources. In addition, a three-month dry spell will significantly increase the risk of high dust loads in the atmosphere during strong winds, and of possible soil loss from vulnerable areas such as cultivated fields following heavy rainfall.

More serious droughts occur when the low rainfall period covers two consecutive seasons such as spring and summer (about six months), or extends to most of the growing season (nine months).

The range of low rainfall periods has been selected in this way to provide a reasonable number of examples of the rainfall amounts that were recorded during the major droughts of this century.

4.3 Probability of drought

The probability of drought occurrence can be determined from the tables given below, depending on how the drought is defined. A range of data are shown on the tables in order to show the average recurrence intervals for a wide variety of drought durations.

In some drought definitions, the *severity* of a drought is associated with its duration (3, 6, 9 months, etc), and the *intensity* of a drought is associated with how much rain fell. Both aspects of drought are important, and hence both the duration in months and the rainfall depth, in millimetres, are shown in the tables.

In the first example, at Wairoa, there were 151 mm of rain in the three months from September to November, 1914. This was about 50% of the three-month average (0.51) and the average return period, or average recurrence interval (ARI), was estimated to be 11 years. The ARI has been determined using probabilities as found from within the total length of the data record. (See page 39 for further definition.)

Further explanation of each column of the tables is given preceding the tables (Section 4.4).

Relationship between ARI and rainfall percent

It is reasonable to expect that the relationship between the ARI and percentage of average rainfall for observed events could be applied generally to determine the relative frequency of low rainfalls at Hawke's Bay sites. This relationship has not been tested here, but a preliminary example with a selected sub-set of data is shown below (Figure 4.4).

The figure suggests that a summer with 30% of average rainfall at these sites would be about a 1 in 20 year event, while 20% of average rainfall would be recorded only about once in 40-50 years. Note that the five sites were composited for this analysis, and the relationship will vary from site to site. Further examination of the data should be undertaken to determine whether the relationship shown below is typical at individual sites, and for other durations and seasons.

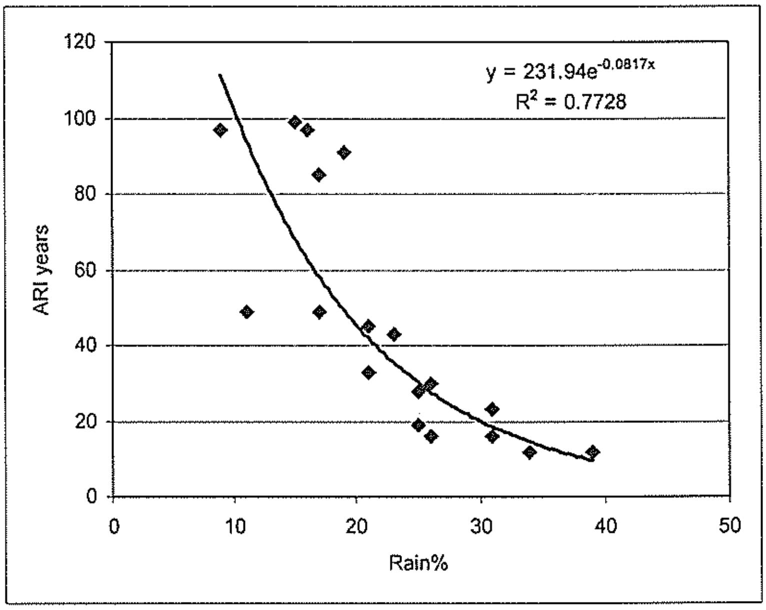


Figure 4.4 Example relationship between average recurrence interval (ARI) and percentage of average rainfall for four summer droughts (Dec-Feb) in Hawke's Bay. The data are taken from the low rainfall tables shown on the following pages, for the three month periods beginning December.

4.4 Low rainfall data tables

An explanation of the content of the tables is given below.

SEQ. MT This is the number of months considered in each period, beginning with the month shown. Eg. **JUL 1914 03** indicates the three month period July-August, 1914

TOTAL mm The total rainfall that was recorded over each period respectively.

RATIO TOT/MEAN The total rainfall recorded, divided by the mean rainfall for the period for all years. This gives an indication of how different the rainfall for the dry period was to the mean.

%'ile This is the ranked value (in ascending order), expressed as a percentile, for all periods beginning with the specified month.

$$\%'ile = \frac{ranked\ value}{number\ of\ obs} * 100$$

ARI Average recurrence interval (or average return period), which is the average number of years between events of the specified size or larger, calculated from within the period of the observed data.

$$ARI = \frac{1}{\%'ile} * 100$$

OBS The number of complete periods beginning with the specified month that were available in the climate record (in effect, the number of years of observations).

4.4.1 The drought of 1914-15

STATION D97031 WAIROA,WAIPUTAPUTA STN

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
JUL 1914	03	137	0.35	3.4	29	87
AUG 1914	03	144	0.41	5.7	17	87
SEP 1914	03	151	0.51	9.3	11	86
NOV 1914	03	120	0.42	9.4	11	85
DEC 1914	03	112	0.34	8.2	12	85
APR 1915	03	252	0.56	8.0	12	87
JUL 1914	06	280	0.41	3.5	29	86
AUG 1914	06	264	0.42	2.4	43	85
SEP 1914	06	263	0.42	4.7	21	85
APR 1915	06	496	0.59	4.7	22	86
MAY 1915	06	530	0.66	6.9	15	87
JUN 1915	06	522	0.71	12.8	8	86
APR 1915	09	754	0.67	4.7	21	85
MAY 1915	09	755	0.69	10.6	9	85
JUN 1915	09	701	0.66	8.2	12	85

STATION D96281 TUTIRA

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
JUL 1914	03	93	0.24	1.1	91	91
AUG 1914	03	87	0.27	1.1	91	91
SEP 1914	03	57	0.21	1.1	92	92
OCT 1914	03	72	0.27	1.1	92	92
NOV 1914	03	91	0.34	3.3	30	90
DEC 1914	03	90	0.31	4.4	23	91
JUL 1914	06	165	0.25	1.1	91	91
AUG 1914	06	178	0.30	1.1	89	89
SEP 1914	06	147	0.26	1.1	90	90
OCT 1914	06	301	0.50	7.8	13	90
NOV 1914	06	297	0.47	7.8	13	90
DEC 1914	06	291	0.42	3.4	30	89
APR 1915	06	465	0.59	7.9	13	89
MAY 1915	06	509	0.67	13.5	7	89
JUL 1914	09	394	0.40	1.1	89	89
AUG 1914	09	384	0.40	1.1	89	89
SEP 1914	09	348	0.36	1.1	88	88
OCT 1914	09	545	0.55	3.4	29	88
NOV 1914	09	613	0.58	9.1	11	88
DEC 1914	09	667	0.61	9.1	11	88
JAN 1915	09	694	0.63	11.2	9	89
FEB 1915	09	715	0.64	11.2	9	89
APR 1915	09	751	0.71	14.6	7	89

STATION D96591 NAPIER NELSON PK

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
JUL 1914	03	54	0.24	1.0	98	98
AUG 1914	03	55	0.30	1.0	98	98
SEP 1914	03	49	0.31	2.0	49	98
OCT 1914	03	50	0.31	3.1	33	98
NOV 1914	03	75	0.46	18.4	5	98
DEC 1914	03	56	0.31	6.2	16	97
JUL 1914	06	104	0.27	1.0	98	98
AUG 1914	06	130	0.37	2.0	49	98
SEP 1914	06	105	0.31	2.1	49	97
OCT 1914	06	220	0.61	15.5	6	97
NOV 1914	06	218	0.59	11.5	9	96
DEC 1914	06	213	0.53	6.3	16	96
JAN 1915	06	312	0.73	19.4	5	98
APR 1915	06	300	0.66	8.2	12	98
JUL 1914	09	274	0.47	2.1	49	97
AUG 1914	09	273	0.49	3.1	32	96
SEP 1914	09	262	0.46	2.1	48	96
OCT 1914	09	362	0.61	7.3	14	96
NOV 1914	09	424	0.68	11.5	9	96
DEC 1914	09	452	0.69	12.5	8	96
JAN 1915	09	470	0.72	11.3	9	97
FEB 1915	09	475	0.73	14.4	7	97

STATION D96771 KOPARAKORE

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
JUL 1914	03	56	0.27	1.0	97	97
AUG 1914	03	51	0.29	1.0	97	97
SEP 1914	03	45	0.29	1.0	97	97
OCT 1914	03	40	0.25	2.1	49	97
NOV 1914	03	44	0.28	5.2	19	97
DEC 1914	03	15	0.09	1.0	97	97
JUL 1914	06	96	0.26	1.0	97	97
AUG 1914	06	95	0.28	1.0	97	97
SEP 1914	06	60	0.19	1.0	97	97
OCT 1914	06	152	0.45	5.2	19	97
NOV 1914	06	162	0.47	4.1	24	97
DEC 1914	06	168	0.45	3.1	32	97
JAN 1915	06	277	0.71	17.3	6	98
APR 1915	06	296	0.70	16.5	6	97
JUL 1914	09	208	0.38	1.0	97	97
AUG 1914	09	213	0.41	1.0	97	97
SEP 1914	09	213	0.41	1.0	97	97
OCT 1914	09	317	0.58	4.1	24	97
NOV 1914	09	359	0.62	6.2	16	97
DEC 1914	09	386	0.64	8.2	12	97
JAN 1915	09	408	0.68	11.3	9	97
FEB 1915	09	436	0.72	15.5	6	97

STATION D96951 MT VERNON 2

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
JUL 1914	03	61	0.27	1.0	99	99
AUG 1914	03	56	0.28	1.0	99	99
SEP 1914	03	46	0.26	1.0	99	99
OCT 1914	03	53	0.28	1.0	99	99
NOV 1914	03	54	0.29	3.0	33	99
DEC 1914	03	29	0.15	1.0	99	99
JAN 1915	03	118	0.60	16.0	6	100
JUL 1914	06	114	0.27	1.0	99	99
AUG 1914	06	110	0.28	1.0	99	99
SEP 1914	06	75	0.20	1.0	99	99
OCT 1914	06	171	0.45	3.0	33	99
NOV 1914	06	182	0.47	3.0	33	99
DEC 1914	06	199	0.48	4.0	25	99
JAN 1915	06	283	0.67	7.0	14	100
FEB 1915	06	347	0.76	18.0	6	100
APR 1915	06	309	0.68	6.1	17	99
MAY 1915	06	339	0.75	13.1	8	99
JUL 1914	09	232	0.38	1.0	99	99
AUG 1914	09	238	0.41	1.0	99	99
SEP 1914	09	245	0.42	1.0	99	99
OCT 1914	09	336	0.55	2.0	50	99
NOV 1914	09	401	0.62	3.0	33	99
DEC 1914	09	429	0.65	5.1	20	99
JAN 1915	09	427	0.65	5.1	20	99
FEB 1915	09	467	0.72	7.1	14	99
APR 1915	09	478	0.74	10.1	10	99
MAY 1915	09	486	0.76	14.1	7	99
JUN 1915	09	508	0.81	17.2	6	99

4.4.2 The drought of 1945-46

STATION D97031 WAIROA,WAIPUTAPUTA SN

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
MAY 1945	03	297	0.65	10.2	10	88
JUN 1945	03	192	0.44	4.5	22	88
JUL 1945	03	150	0.38	4.6	22	87
AUG 1945	03	204	0.58	14.9	7	87
SEP 1945	03	145	0.49	8.1	12	86
OCT 1945	03	127	0.44	7.0	14	86
NOV 1945	03	78	0.27	2.4	43	85
DEC 1945	03	76	0.23	2.4	43	85
JUL 1946	03	180	0.46	6.9	15	87
AUG 1946	03	209	0.60	16.1	6	87
APR 1945	06	469	0.56	3.5	29	86
MAY 1945	06	501	0.62	3.4	29	87
JUN 1945	06	337	0.46	3.5	29	86
JUL 1945	06	277	0.41	2.3	43	86
AUG 1945	06	282	0.44	3.5	28	85
SEP 1945	06	221	0.36	2.4	43	85
OCT 1945	06	391	0.59	12.9	8	85
JUL 1946	06	339	0.50	5.8	17	86
APR 1945	09	596	0.53	2.4	43	85
MAY 1945	09	579	0.53	1.2	85	85
JUN 1945	09	413	0.39	1.2	85	85
JUL 1945	09	541	0.51	3.5	28	85

STATION D96281 TUTIRA

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
MAY 1945	03	238	0.55	15.6	6	90
JUN 1945	03	204	0.49	5.5	18	91
OCT 1945	03	141	0.53	13.0	8	92
NOV 1945	03	58	0.22	1.1	90	90
DEC 1945	03	54	0.19	1.1	91	91
JAN 1946	03	69	0.21	3.3	31	92
JUL 1946	03	221	0.58	19.8	5	91
APR 1945	06	484	0.62	10.1	10	89
MAY 1945	06	541	0.72	19.1	5	89
JUN 1945	06	403	0.59	3.3	30	91
JUL 1945	06	399	0.61	8.8	11	91
AUG 1945	06	361	0.61	13.5	7	89
SEP 1945	06	253	0.45	3.3	30	90
OCT 1945	06	210	0.35	1.1	90	90
NOV 1945	06	336	0.54	11.1	9	90
JUL 1946	06	399	0.61	9.9	10	91
APR 1945	09	625	0.59	2.2	45	89
MAY 1945	09	599	0.58	3.4	29	88
JUN 1945	09	457	0.46	2.2	45	89
JUL 1945	09	468	0.47	3.4	30	89
AUG 1945	09	639	0.67	13.5	7	89

STATION D96591 NAPIER NELSON PK

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
MAY 1945	03	167	0.66	19.2	5	99
JUN 1945	03	120	0.48	6.1	17	99
JUL 1945	03	146	0.66	16.3	6	98
OCT 1945	03	89	0.55	15.3	7	98
NOV 1945	03	29	0.18	1.0	98	98
DEC 1945	03	28	0.16	1.0	97	97
JAN 1946	03	69	0.35	7.1	14	99
JUL 1946	03	123	0.55	8.2	12	98
APR 1945	06	305	0.67	11.2	9	98
JUN 1945	06	245	0.60	4.1	25	98
JUL 1945	06	235	0.61	7.1	14	98
AUG 1945	06	218	0.63	16.3	6	98
SEP 1945	06	153	0.45	5.2	19	97
OCT 1945	06	158	0.44	4.1	24	97
NOV 1945	06	218	0.59	12.5	8	96
JUL 1946	06	242	0.63	8.2	12	98
AUG 1946	06	217	0.62	15.3	7	98
APR 1945	09	394	0.64	2.0	49	98
MAY 1945	09	385	0.64	7.1	14	98
JUN 1945	09	273	0.47	2.1	49	97
JUL 1945	09	304	0.52	5.2	19	97
AUG 1945	09	407	0.73	17.7	6	96
JUL 1946	09	417	0.72	15.5	6	97

STATION D96771 KOPARAKORE

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
APR 1945	03	139	0.64	19.4	5	98
MAY 1945	03	145	0.61	10.2	10	98
JUN 1945	03	162	0.69	19.4	5	98
OCT 1945	03	67	0.41	8.2	12	97
NOV 1945	03	19	0.12	1.0	97	97
DEC 1945	03	18	0.11	2.1	49	97
JAN 1946	03	77	0.44	9.2	11	98
JUL 1946	03	136	0.65	18.6	5	97
JUN 1945	06	279	0.71	14.4	7	97
JUL 1945	06	251	0.68	10.3	10	97
AUG 1945	06	226	0.67	16.5	6	97
SEP 1945	06	135	0.42	3.1	32	97
OCT 1945	06	144	0.43	4.1	24	97
NOV 1945	06	178	0.52	8.2	12	97
JUL 1946	06	242	0.65	9.3	11	97
AUG 1946	06	236	0.70	19.6	5	97
APR 1945	09	390	0.67	7.2	14	97
MAY 1945	09	371	0.65	7.2	14	97
JUN 1945	09	297	0.53	3.1	32	97
JUL 1945	09	328	0.60	5.2	19	97
AUG 1945	09	385	0.74	14.4	7	97

STATION D96951 MT VERNON 2

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
MAY 1945	03	179	0.71	19.0	5	100
JUN 1945	03	165	0.66	15.0	7	100
SEP 1945	03	84	0.47	6.1	17	99
OCT 1945	03	61	0.33	3.0	33	99
NOV 1945	03	41	0.22	2.0	50	99
DEC 1945	03	41	0.21	3.0	33	99
JAN 1946	03	100	0.51	11.0	9	100
JUL 1946	03	85	0.37	2.0	50	99
AUG 1946	03	104	0.53	8.1	12	99
SEP 1946	03	113	0.64	16.2	6	99
OCT 1946	03	107	0.57	19.2	5	99
APR 1945	06	353	0.77	18.2	6	99
MAY 1945	06	344	0.76	15.2	7	99
JUN 1945	06	249	0.58	2.0	50	99
JUL 1945	06	228	0.55	4.0	25	99
AUG 1945	06	206	0.53	6.1	17	99
SEP 1945	06	125	0.34	2.0	50	99
OCT 1945	06	161	0.42	1.0	99	99
NOV 1945	06	203	0.52	7.1	14	99
JUN 1946	06	296	0.69	8.1	12	99
JUL 1946	06	192	0.46	2.0	50	99
AUG 1946	06	184	0.48	2.0	50	99
SEP 1946	06	266	0.71	17.2	6	99
APR 1945	09	414	0.64	3.0	33	99
MAY 1945	09	385	0.60	1.0	99	99
JUN 1945	09	290	0.46	2.0	50	99
JUL 1945	09	328	0.54	4.0	25	99
AUG 1945	09	368	0.63	7.1	14	99
SEP 1945	09	440	0.75	13.1	8	99
NOV 1945	09	505	0.79	16.2	6	99
DEC 1945	09	539	0.81	18.2	6	99
JAN 1946	09	528	0.81	14.1	7	99
MAY 1946	09	486	0.76	15.2	7	99
JUN 1946	09	449	0.72	8.1	12	99
JUL 1946	09	391	0.64	6.1	17	99
AUG 1946	09	443	0.75	13.1	8	99

4.4.3 The drought of 1982-83

STATION D97031 WAIROA, WAIPUTAPUTA SN

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
NOV 1982	03	95	0.33	5.9	17	85
DEC 1982	03	56	0.17	1.2	85	85
JAN 1983	03	56	0.15	1.1	87	87
JUL 1982	06	484	0.71	17.4	6	86
AUG 1982	06	421	0.66	16.5	6	85
SEP 1982	06	366	0.59	10.6	9	85
OCT 1982	06	242	0.36	1.2	85	85
NOV 1982	06	378	0.53	7.2	14	83
DEC 1982	06	488	0.63	13.3	8	83
JAN 1983	06	537	0.66	14.1	7	85
MAY 1982	09	821	0.75	12.9	8	85
JUN 1982	09	752	0.71	12.9	8	85
JUL 1982	09	540	0.51	2.4	43	85
AUG 1982	09	704	0.66	15.7	6	83
OCT 1982	09	723	0.65	12.0	8	83
NOV 1982	09	822	0.71	15.7	6	83
DEC 1982	09	883	0.73	16.9	6	83
JAN 1983	09	909	0.75	13.1	8	84

STATION D96281 TUTIRA

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
MAY 1982	03	204	0.47	7.8	13	90
JUN 1982	03	216	0.52	9.9	10	91
JUL 1982	03	171	0.44	8.8	11	91
AUG 1982	03	175	0.54	14.3	7	91
NOV 1982	03	95	0.36	5.6	18	90
DEC 1982	03	62	0.21	2.2	45	91
JAN 1983	03	52	0.16	1.1	92	92
JUN 1983	03	246	0.59	17.6	6	91
JUL 1983	03	156	0.41	6.6	15	91
MAY 1982	06	379	0.50	1.1	89	89
JUN 1982	06	423	0.62	6.6	15	91
JUL 1982	06	342	0.52	4.4	23	91
AUG 1982	06	270	0.45	3.4	30	89
SEP 1982	06	269	0.48	4.4	22	90
OCT 1982	06	223	0.37	2.2	45	90
NOV 1982	06	318	0.51	8.9	11	90
DEC 1982	06	327	0.48	5.6	18	89
JAN 1983	06	417	0.57	11.1	9	90
FEB 1983	06	505	0.64	17.8	6	90
MAR 1983	06	511	0.63	19.1	5	89
APR 1983	06	521	0.66	14.6	7	89
MAY 1983	06	500	0.66	11.2	9	89
JUN 1983	06	471	0.69	14.3	7	91
JUL 1983	06	442	0.68	17.6	6	91
APR 1982	09	766	0.73	16.9	6	89
MAY 1982	09	474	0.46	1.1	88	88
JUN 1982	09	485	0.49	3.4	30	89
JUL 1982	09	394	0.40	2.2	45	89
AUG 1982	09	493	0.52	2.2	45	89
SEP 1982	09	534	0.55	5.7	18	88
OCT 1982	09	588	0.59	6.8	15	88
NOV 1982	09	600	0.57	6.8	15	88
DEC 1982	09	573	0.52	3.4	29	88
JAN 1983	09	573	0.52	3.4	30	89
FEB 1983	09	723	0.65	12.4	8	89
MAR 1983	09	736	0.68	12.4	8	89
MAY 1983	09	726	0.71	13.6	7	88

STATION D96591 NAPIER NELSON PK

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
JUL 1982	03	126	0.57	10.2	10	98
AUG 1982	03	93	0.50	11.2	9	98
OCT 1982	03	81	0.50	11.2	9	98
NOV 1982	03	64	0.39	10.2	10	98
DEC 1982	03	30	0.17	2.1	49	97
JAN 1983	03	27	0.14	1.0	99	99
FEB 1983	03	80	0.38	10.2	10	98
JUN 1983	03	159	0.64	18.2	6	99
JUL 1983	03	121	0.55	7.1	14	98
MAY 1982	06	283	0.64	6.1	16	98
JUN 1982	06	298	0.73	17.3	6	98
JUL 1982	06	207	0.54	5.1	20	98
AUG 1982	06	157	0.45	4.1	25	98
SEP 1982	06	149	0.44	4.1	24	97
OCT 1982	06	108	0.30	1.0	97	97
NOV 1982	06	144	0.39	4.2	24	96
DEC 1982	06	162	0.40	3.1	32	96
JAN 1983	06	204	0.48	3.1	33	98
FEB 1983	06	268	0.58	8.2	12	98
MAR 1983	06	291	0.61	12.1	8	99
APR 1983	06	298	0.66	7.1	14	98
APR 1982	09	465	0.75	19.4	5	98
MAY 1982	09	347	0.58	1.0	98	98
JUN 1982	09	328	0.56	3.1	32	97
JUL 1982	09	234	0.40	1.0	97	97
AUG 1982	09	237	0.43	1.0	96	96
SEP 1982	09	281	0.50	4.2	24	96
OCT 1982	09	285	0.48	3.1	32	96
NOV 1982	09	332	0.53	3.1	32	96
DEC 1982	09	321	0.49	1.0	96	96
JAN 1983	09	325	0.50	1.0	97	97
FEB 1983	09	465	0.72	12.4	8	97
MAR 1983	09	479	0.76	19.4	5	98

STATION D96771 KOPARAKORE

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
JUL 1982	03	95	0.46	5.2	19	97
AUG 1982	03	58	0.32	2.1	49	97
SEP 1982	03	93	0.60	13.4	7	97
OCT 1982	03	92	0.57	17.5	6	97
NOV 1982	03	82	0.52	19.6	5	97
DEC 1982	03	44	0.26	6.2	16	97
JAN 1983	03	35	0.20	2.0	49	98
FEB 1983	03	87	0.47	13.3	8	98
JUN 1983	03	143	0.61	10.2	10	98
JUL 1983	03	83	0.40	4.1	24	97
APR 1982	06	284	0.67	13.4	7	97
MAY 1982	06	249	0.60	5.2	19	97
JUN 1982	06	281	0.72	15.5	6	97
JUL 1982	06	187	0.51	3.1	32	97
AUG 1982	06	140	0.42	3.1	32	97
SEP 1982	06	137	0.42	4.1	24	97
OCT 1982	06	127	0.38	2.1	49	97
NOV 1982	06	169	0.49	6.2	16	97
DEC 1982	06	179	0.48	5.2	19	97
JAN 1983	06	243	0.62	8.2	12	98
FEB 1983	06	280	0.66	14.3	7	98
MAR 1983	06	278	0.64	10.2	10	98
APR 1983	06	291	0.69	14.4	7	97
APR 1982	09	376	0.64	5.2	19	97
MAY 1982	09	331	0.58	2.1	49	97
JUN 1982	09	325	0.58	4.1	24	97
JUL 1982	09	222	0.41	2.1	49	97
AUG 1982	09	227	0.44	2.1	49	97
SEP 1982	09	272	0.52	4.1	24	97
OCT 1982	09	335	0.61	8.2	12	97
NOV 1982	09	362	0.62	7.2	14	97
DEC 1982	09	322	0.53	2.1	49	97
JAN 1983	09	326	0.55	3.1	32	97
FEB 1983	09	437	0.72	16.5	6	97
MAR 1983	09	442	0.75	18.6	5	97
MAY 1983	09	448	0.78	17.5	6	97
JUN 1983	09	446	0.80	19.6	5	97

STATION D96951 MT VERNON 2

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
JUL 1982	03	143	0.63	13.1	8	99
AUG 1982	03	102	0.52	7.1	14	99
NOV 1982	03	95	0.51	15.2	7	99
DEC 1982	03	76	0.39	8.1	12	99
JAN 1983	03	55	0.28	2.0	50	100
FEB 1983	03	97	0.48	11.0	9	100
JUN 1983	03	143	0.57	7.0	14	100
JUL 1983	03	123	0.54	6.1	17	99
JUL 1982	06	262	0.63	9.1	11	99
AUG 1982	06	197	0.51	4.0	25	99
SEP 1982	06	203	0.54	6.1	17	99
OCT 1982	06	174	0.45	4.0	25	99
NOV 1982	06	192	0.49	6.1	17	99
DEC 1982	06	270	0.66	9.1	11	99
JAN 1983	06	327	0.77	18.0	6	100
FEB 1983	06	344	0.76	16.0	6	100
MAR 1983	06	337	0.72	14.0	7	100
APR 1982	09	501	0.78	17.2	6	99
MAY 1982	09	456	0.71	8.1	12	99
JUN 1982	09	455	0.73	9.1	11	99
JUL 1982	09	317	0.52	3.0	33	99
AUG 1982	09	294	0.50	2.0	50	99
SEP 1982	09	397	0.67	8.1	12	99
OCT 1982	09	446	0.73	12.1	8	99
NOV 1982	09	439	0.68	7.1	14	99
DEC 1982	09	413	0.62	3.0	33	99
JAN 1983	09	450	0.69	7.1	14	99

4.4.4 The drought of 1997-98

STATION D97031 WAIROA,WAIPUTAPUTA SN

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
NOV 1997	03	102	0.36	7.1	14	85
DEC 1997	03	81	0.25	3.5	28	85
JAN 1998	03	89	0.24	2.3	44	87
FEB 1998	03	94	0.23	1.2	85	85
MAR 1998	03	132	0.30	2.3	43	86
APR 1998	03	233	0.51	5.7	17	87
OCT 1997	06	332	0.50	4.7	21	85
NOV 1997	06	196	0.28	1.2	83	83
DEC 1997	06	213	0.28	1.2	83	83
JAN 1998	06	322	0.39	1.2	85	85
FEB 1998	06	467	0.54	2.4	43	85
MAR 1998	06	561	0.64	7.0	14	86
APR 1998	06	565	0.67	9.3	11	86
MAY 1998	06	530	0.66	8.0	12	87
SEP 1997	09	660	0.62	8.4	12	83
OCT 1997	09	565	0.51	2.4	42	83
NOV 1997	09	569	0.49	2.4	42	83
DEC 1997	09	642	0.53	2.4	42	83
JAN 1998	09	654	0.54	2.4	42	84
FEB 1998	09	624	0.51	1.2	84	84
MAR 1998	09	692	0.59	3.6	28	84
APR 1998	09	764	0.67	5.9	17	85

STATION D96281 TUTIRA

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
NOV 1997	03	104	0.39	7.8	13	90
DEC 1997	03	75	0.26	3.3	30	91
JAN 1998	03	66	0.20	2.2	46	92
FEB 1998	03	80	0.23	2.2	46	93
OCT 1997	06	234	0.39	3.3	30	90
NOV 1997	06	184	0.29	1.1	90	90

STATION D96591 NAPIER NELSON PK

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
NOV 1997	03	53	0.33	4.1	25	98
DEC 1997	03	45	0.25	5.2	19	97
JAN 1998	03	47	0.24	2.0	50	99
FEB 1998	03	56	0.27	5.1	20	98
MAR 1998	03	67	0.30	3.0	33	99
APR 1998	03	84	0.36	2.0	50	99
OCT 1997	06	148	0.41	3.1	32	97
NOV 1997	06	109	0.29	1.0	96	96
DEC 1997	06	112	0.28	1.0	96	96
JAN 1998	06	131	0.31	1.0	98	98
SEP 1997	09	306	0.54	5.2	19	96
OCT 1997	09	232	0.39	1.0	96	96
NOV 1997	09	369	0.59	7.3	14	96
DEC 1997	09	389	0.60	6.3	16	96
JAN 1998	09	394	0.61	7.2	14	97
FEB 1998	09	386	0.59	3.1	32	97
MAR 1998	09	418	0.66	9.2	11	98

STATION D96771 KOPARAKORE

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
NOV 1997	03	48	0.31	6.2	16	97
JAN 1998	03	50	0.29	4.1	25	98
FEB 1998	03	52	0.28	4.1	25	98
MAR 1998	03	58	0.29	2.0	49	98
APR 1998	03	79	0.37	4.1	25	98
OCT 1997	06	155	0.46	6.2	16	97
NOV 1997	06	100	0.29	2.1	49	97
DEC 1997	06	117	0.32	2.1	49	97
JAN 1998	06	129	0.33	1.0	98	98
FEB 1998	06	259	0.61	9.2	11	98
MAR 1998	06	271	0.62	8.2	12	98
APR 1998	06	272	0.64	8.2	12	97
MAY 1998	06	275	0.66	9.3	11	97
JUL 1997	09	361	0.66	7.2	14	97
SEP 1997	09	284	0.54	5.2	19	97
OCT 1997	09	234	0.43	1.0	97	97
NOV 1997	09	307	0.53	2.1	49	97
DEC 1997	09	330	0.55	3.1	32	97
JAN 1998	09	322	0.54	2.1	49	97
FEB 1998	09	327	0.54	1.0	97	97
MAR 1998	09	331	0.56	2.1	49	97
APR 1998	09	365	0.62	4.1	24	97

STATION D96951 MT VERNON 2

	SEQ. MT	TOTAL mm	RATIO TOT/MEAN	%ile	ARI	OBS
MAR 1998	03	94	0.43	5.0	20	100
NOV 1997	06	184	0.47	4.0	25	99
DEC 1997	06	211	0.51	5.1	20	99
JAN 1998	06	235	0.55	4.0	25	100
MAR 1998	06	312	0.67	7.0	14	100
MAY 1998	06	323	0.72	9.1	11	99
OCT 1997	09	389	0.64	5.1	20	99
NOV 1997	09	425	0.66	4.0	25	99
DEC 1997	09	429	0.65	6.1	17	99
JAN 1998	09	416	0.64	4.0	25	99
FEB 1998	09	415	0.64	2.0	50	99
MAR 1998	09	415	0.64	3.0	33	99
APR 1998	09	446	0.69	6.1	17	99

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Addendum: Hail risk

Following the drafting of this report HBEL requested additional information on hail risk in Hawke's Bay. The paper *New Zealand Hailstorms* by the late Tom Steiner is attached. The paper includes information on hailstorms and the risk of hail in Hawke's Bay.